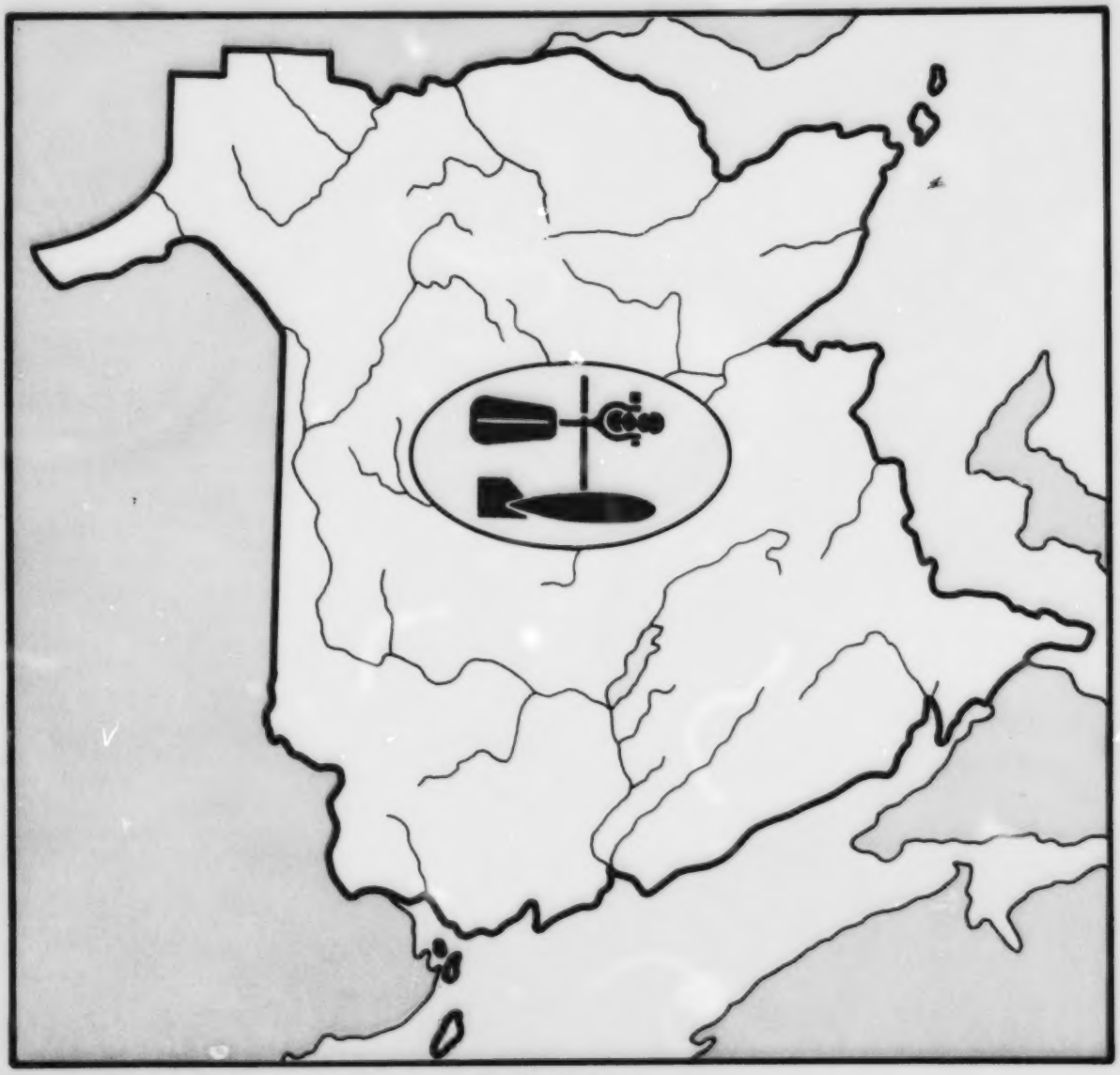
New Brunswick
Hydrometric Network Evaluation

Background Report No. 3
Regional Hydrology and Data Transfer Methodologies



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NEW BRUNSWICK HYDROMETRIC NETWORK EVALUATION

BACKGROUND REPORT NO. 3

REGIONAL HYDROLOGY
AND
DATA TRANSFER METHODOLOGIES

A REPORT PREPARED BY THE
REGIONAL HYDROLOGY AND DATA TRANSFER SUBCOMMITTEE
NEW BRUNSWICK HYDROMETRIC NETWORK EVALUATION PROJECT

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ABSTRACT

In order to assess the ability of the New Brunswick hydrometric network to transfer data from gauged to ungauged sites, a regional hydrology study was undertaken. It was decided that regional regression equations provided the most appropriate approach and these were performed for mean, low and high flows. The transfer of daily flows with flow duration curves was also investigated. The various studies lead to mean, low and high flow hydrologic regions as well as indications as to the deficiencies in the network. Based on these findings, a proposal was prepared for a minimum regional hydrology network as well as for a target or optimal regional hydrology network.

RESUME

Afin d'évaluer la capabilité de transfert de données d'un site jaugé à un site non-jaugé par le réseau hydrométrique du Nouveau-Brunswick, une étude d'hydrologie régionale fut entreprise. On décida que les équations régionales par régression fournissaient l'approache la plus appropriée, et celles-ci furent générées pour les débits moyens, bas et hauts. Le transfert de débits journaliers à base de courbes de duration des débits fut aussi examiné. Les diverses études ont produites des régions hydrologiques pour les débits moyens, bas et hauts de même que des indications sur les faiblesses du réseau. Basé sur ces découvertes, on proposa un réseau minimum d'hydrologie régionale ainsi qu'un réseau cible ou optimal d'hydrologie régionale.

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1.0 INTRODUCTION

The New Brunswick Hydrometric Network Evaluation was a two-year study of the requirements for a hydrometric network in New Brunswick and an evaluation of the existing hydrometric network with consideration of these requirements. The purpose of this study was to evaluate the effectiveness of water resources monitoring. A series of background reports examines various aspects of the study, with regional hydrology, the topic of this volume, being one of them.

The regional hydrology network is a sub-network of the hydrometric network and is generally made up of a selection of all the gauging stations of the network that monitor unregulated, natural flows. The term "regional" is used here in the context of areas of similarity with regard to the hydrology and should not be confused with administrative boundaries. The Province of New Brunswick can be divided into several regions, whose boundaries depend on the characteristics of the various components of the flow regime. The main purpose of a regional hydrology network is to measure representative streams of a region and ideally provide sufficient data to predict, within a prescribed degree of accuracy, the hydrologic characteristics at those locations which are not monitored. The selection of the stations to represent the region is critical to the performance of the network and represents a balance between insufficient and redundant data.

From time to time, it is important that the entire hydrometric network be assessed to determine if it is meeting user needs for water resources data. A major part of this is the analysis of the regional hydrology network. To perform this task, the network must be viewed in the context of a collection of select stations which are required to define one or more hydrologic regions.

The data from regional hydrology stations are extremely important to the development of data transfer methods. For example, the transfer of information, such as the magnitude of the 1:20 year flood flow or the mean monthly flow, from the known network stations to some ungauged site within the region requires a representative sample from which a transfer function can be developed. The importance here is to have a sufficient number of stations that represent the variations of the hydrologic regimes of the region.

The main thrust of this report is to determine the hydrologic regions given the information available to date

and to assess the importance of each station to its region in terms of how well hydrologic information can be transferred. Gaps in network coverage, the location of these gaps, and the means to fill them are identified.

These findings will be used to evaluate the existing network and to suggest locations for new stations. A regional hydrology priority code derived in this report will input directly into a network evaluation tool called the Station Audit exercise detailed in the Principal Network Evaluation Report of this series. The Station Audit exercise will be used to collectively evaluate all types of stations in the network, not just the regional hydrology stations. Based on various assumptions regarding the goals of the network, a number of alternate scenarios for the network will be generated in this exercise for submission to the network managers.

2.0 DATA ACCURACY REQUIREMENTS

In determining the effectiveness of the regional hydrology network, it is important that an accuracy goal or objective be considered. This objective should relate to the raw data, the information determined from that data, as well as the transfer of information to ungauged sites.

To help determine the objective accuracy level, the client or the data user is often asked to state their accuracy requirements. The answers invariably received are, "As accurate as you can give them to us" or " How accurate are they now?" Both of these responses are vague generalities and the answers are often just as general or they vary with time and space, depending upon the immediate perceived need.

Each piece of data has associated with it some magnitude of error or a degree of accuracy if you prefer, which is a combination of a number of independent and systematic errors many of which are not always known.

2.1 FACTORS AFFECTING ACCURACY

A number of factors affect the accuracy of streamflow data, some involving the data measurement process and others the data interpretation methodology.

The accuracy associated with the actual discharge measurement has been shown to be a function of the reliability of the meter rating, the flow conditions at the time, and the number of velocity measurements taken. Winter measurements are more uncertain because it is difficult to properly determine the effective flow area and the effect of backwater from the ice cover.

Accuracy of the data is greatly influenced by the availability of a good gauging site. The quality of the stream gauge control throughout the hydraulic regime is a major factor in data accuracy. The presence of backwater from time to time, whether due to ice, weeds or other downstream constrictions, reduces the accuracy of the stage-discharge rating curve and is a major concern if only on a seasonal basis. Some sites have higher than normal variation associated with their extreme (high and low) flow events due to the flashiness of the stream or a deep gravel bed which may pass flows undetected.

The frequency of station visitation and stage-discharge measurements also influence the accuracy of the rating curve. The loss of data accuracy due to gauge shifts and

backwater are directly related to the number of station visits, as is the loss of actual data to malfunction in the recording mechanism.

The raw water data are comprised of water levels recorded on analogue strip charts. These must be documented for time and elevation shift. As the data is transformed from analogue to digital form to produce computer readable data, the digitizer operator must maintain the standard for accuracy to avoid errors being made on this original record.

2.2 DATA INTERPRETATION AND TRANSFER

An increased effort is being made to extend the use of the raw data through interpretive studies. Through the effective use of computers, more analyses of the data can and are being performed than were ever possible before.

Information on the frequency of low flows and flood flows or the shape of the flow duration curve can be of great benefit during the planning and design phase of a hydraulic structure or a water management scheme. The errors associated with the methods used to model the data are not only factors of the data, but also the models themselves. The ability of the models to fit the data set are often a function of the length of record and the stability of the natural watershed over time. The applicability of the model is a major factor in achieving an acceptable degree of accuracy.

The data collected at each station begin to be useful for statistical analysis after they have been recorded for 10 to 15 years but they only become significantly useful when they have been accumulated for 25 to 30 years. One reason for this requirement is that most of the statistical models used in hydrology assume that the data, or some transform of the data such as natural logarithms, are normally distributed. Even if this assumption is incorrect, the normal distribution can be used to approximate the sample mean and standard deviation of the data (or the transforms of the data) as the size of the sample (n) becomes sufficiently large (Central Limit Theorem). In hydrology, this becomes significant as 'n' approaches 30 (Condie,1987).

A serious problem in flood frequency analysis is the fact that many of the annual maximum daily mean flows used are significantly greater than the highest metered flow at the station. As an extreme case, for station 01AP002 (Canaan River at East Canaan), the highest metering occured at 146 m^3/s and the 1:2 year flood estimate is 141 m^3/s. There-

fore, roughly half of the values used in flood frequency analysis for this station are beyond the metered range. The effect this has on the error of the flood estimate of a given return period is unknown, but is undoubtedly significant. This indicates that any standard error generated from a data transfer technique is in reality a minimum indication of the actual uncertainty associated with the data transfer process.

Through interpretive analyses, the estimation of the associated errors of the modelling practices are also being determined. One of the side benefits of these studies is the detection of possible errors associated with procedures dealing with the raw data, many of which can be corrected.

The errors associated with data transfer reflect the uncertainties involved in tranferring the data from gauged to ungauged sites. Through effective network planning, a more representative network can be established; however, the benefits from this are generally long-term. Again, the rapid increase in computer usage allows the inclusion of many other data bases; these include climate, physiography and land use, and are bound to help the overall performance of the network data.

Many important criteria must be met in order to obtain an applicable transfer function. If the data used does not include a full range of small to large (relative to the drainage area) streams, then the function is limited in its applicability to adequately define the hydrologic regime. Such a limited equation may show a small standard error but will not explain the variance over the full range of circumstances and will ultimately fail to meet the overall information needs. The misuse of such equations by extension outside the range of the input data can lead to erroneous results.

The size of the data sample (i.e. the number of stations) must be considered when developing statistical transfer functions. By reducing the network without regard for the natural variation in a region, it is conceivable to develop transfer functions with a lower standard error. If stations which show the full range in variance of the hydrologic regime have not been included, the overall effect will yield a false sense of accuracy and a transfer function which is not necessarily representative of the region. This can lead to large predictive errors in a significant range of ungauged sites over the region.

The stations selected as part of the regional hydrology network must therefore characterize the natural variations in physiography, climate, land use and any other factor likely to influence streamflow. An appropriate range for these factors as found in nature must be sampled. Thus, data accuracy of the regional hydrology network as a whole is increased through the determination of representative stations for the network.

2.3 SUMMARY

Accuracy is a very complex subject. It takes into account all facets of the data collection/reduction structure as well as the tools which are used to interpret the data. No one appears to have a set goal for accuracy, possibly because they have no standard from which to measure. The amount of available data must be considered when undertaking statistical analyses. Ten (10) to 15 years of data at a stations are required for most statistical analyses, however, 25 to 30 years of data makes them significantly more useful. The size of the data sample (number of stations) is also important in developing statistical transfer functions. Selecting representative stations in the network is crucial in obtaining more accurate transferring tools.

3.0 DATA/INFORMATION TRANSFER TECHNIQUES

A major problem in engineering hydrology has always been that streamflow measurements are not usually available at locations where design flows or hydrologic evaluations are required. Therefore, a large part of hydrologic analysis is concerned with synthesizing and transferring information from gauged to ungauged locations. The purpose of this chapter is to review the various hydrologic transfer methods available and assess their applicability to the hydrology of New Brunswick.

There are two classes of techniques that can be utilized to provide streamflow information. The first involves the use of hydrologic or hydraulic models, while the second involves the use of statistical methods. Both classes are described briefly below with discussion of the advantages and disadvantages of individual techniques.

3.1 TECHNIQUES INVOLVING USE OF MODELS

Often what is required is a synthesis of individual flow values or of entire hydrographs, either on small ungauged watersheds or at some point on a larger river between gauged locations. In the former case, a conceptual hydrologic model might be utilized, in the latter a hydrologic or hydraulic flow-routing model.

Conceptual hydrologic models can be used to estimate hourly or daily mean flows and hydrographs of selected storm events or design storms. Such models can extend flood records by calibrating to short-term concurrent streamflow and climatic data, and then simulating annual flood peaks using long-term (60-70 years) precipitation and evaporation data at nearby climatic stations. Flood frequency curves can then be defined using the long-term simulated data.

The availability of suitable climate data and the time to calibrate the model may limit the utility of conceptual hydrologic models in large-scale network analysis. Joint location of meteorological and hydrometric stations would greatly improve the possibility of using models to predict flows at ungauged sites, but additional snow cover data would also be required. If flow data is acceptable with an accuracy less than that obtained with a hydrometric station at the site of interest, models could provide the entire required flow sequence without the need for a hydrometric station on that stream. Unfortunately, the lack of coordination with precipitation, temperature and snow data makes this presently impossible.

Hydrologic flow-routing methods use the law of conservation of mass and the relationship between the storage in and outflow from a river reach. The hydraulics of the system are not considered. The methods usually require only a few parameters, and the reach is not subdivided. A measured discharge hydrograph is required at the upstream end of the reach, and the computations produce a discharge hydrograph at the downstream end. Hydrologic routing methods include the Muskingum, Modified Puls, Kinematic Wave, lag routing, and the unit-response flow-routing methods(Shiau and Steingass, 1985).

Hydraulic flow-routing methods utilize the laws of conservation of mass and momentum to represent unsteady flow conditions. These equations may be solved using finite difference, method of characteristics or finite element computational procedures. Calibration of a hydraulic model for a river reach would permit the estimation of streamflow data at several locations within the reach. Furthermore, these methods are very suitable for providing streamflow data for river reaches subject to variable backwater where conventional gauging procedures may be inadequate.

3.2 TECHNIQUES INVOLVING STATISTICAL METHODS

Simple and multiple-regression techniques also can be used to estimate daily flow records. Unlike hydrologic routing, regression methods are not limited to locations where an upstream station exists on the same stream. Regression equations can be computed that relate daily flows (or their logarithms) at a station (dependent variable) to daily flows at another station or at a combination of upstream, or tributary stations. The independent variables in the regression analysis can include stations from different watersheds.

The regression method is easy to apply, provides indices of accuracy, and is very widely used and accepted in hydrology; the theory and assumptions are described in numerous references such as Draper and Smith (1981) and Pilon and Condie (1983). The application of regression methods to hydrologic problems is described and illustrated by Riggs (1973) and Thomas and Benson (1970).

Orthogonalization of the regression problem using principal components analysis can be utilized when there is multi-collinearity in the independent variables. Regression on principal components is described in several sources (Haan, 1977; Pilon, 1981; Kendall, 1975) and will not be reiterated here.

In many cases, what is required is a broad approach to generate regional streamflow characteristics such as peak flows, low flows and mean annual flows. In this case, it is often best to apply some form of statistical regression technique, e.g. ordinary least squares, weighted least squares or generalized least squares, or perhaps the index flood technique (Dalrymple,1960).

One procedure that has been used as a transfer mechanism for streamflow information is logarithmic regression analysis (Benson and Matalas, 1967; Thomas and Benson, 1970). In this approach, streamflow characteristics are related to a variety of physiographic and climatic parameters that describe the drainage basin and climatic conditions upstream from the station. This analysis results in a relation of the form:

$$Q = b_0 \cdot x_1^{b1} \cdot x_2^{b2} \cdots x_k^{bk}$$

in which Q is an estimate of a streamflow characteristic such as the 10-year flood discharge or the annual mean discharge, x_1, x_2, $\ldots x_k$ are physiographic and climatic parameters that are measurable from topographic maps or are readily available from climatic reports and b_0, b_1, b_2,$\ldots b_k$ are regression coefficients that are defined by regression analysis using data collected at existing gauging stations.

The method traditionally used for computing the regional regression equation is the ordinary least squares (OLS) technique. The OLS model is appropriate when all estimates of streamflows of a given return period have approximately equal variance, and concurrent streamflows at different stations are uncorrelated or independently distributed.

These two assumptions are usually violated to some degree in hydrologic regression analysis because (1) streamflow records for various watersheds are of different lengths and therefore the resultant streamflow characteristics have unequal variances, and (2) streamflow characteristics for nearby watersheds are correlated due to experiencing similar climatic events.

Recent research (Stedinger and Tasker, 1985) has indicated that a new technique, generalized least squares, may be more appropriate for hydrologic regression and network analysis. Generalized least squares eliminates the need for the two assumptions noted above because each watershed in the regional regression analysis is weighted appropriately to take into consideration the variance (time-sampling error)

and spatial correlation structure of the streamflow characteristic. In addition, the time-sampling error in the streamflow characteristic is accounted for in evaluating the accuracy of the regression equation. A more realistic evaluation of the accuracy of the regression equation permits the analyst to better evaluate the worth of additional data collection.

Thomas and Cheng (1985) applied the generalized least squares technique to the Oldman River Basin, Alberta. Ten-year flood discharges were compiled as a function of several physiographic and climatic parameters. The resulting standard errors of estimate were ±55.7% and ±73.6% respectively; however, a large percentage of these errors resulted from the form of model chosen. The authors concluded that improvement in model form offered the greatest potential for more accurately estimating flood discharges at ungauged sites.

3.3 IMPLICATIONS FOR NETWORK EVALUATION

A multitude of other data transfer techniques exist and all of these methods have applications in different hydrologic situations. However, **regression techniques are best because they are the most commonly used data transfer methods, they are relatively easy to apply, they can cover the entire province, and they can serve as an indicator of how well information transfer can be performed.** Techniques such as correlation analysis, routing, and hydrologic modeling can be applied at a more detailed level to optimize the network in a specific basin or river reach.

Regression analysis is more often used to transfer data from one location to another by developing a relationship between a flow parameter and a number of parameters which are considered to influence the flow. The flow parameter could be as simple as the 1:2 year recurrence interval mean annual flow or more complex such as the 1:50 year 10-day mean low flow. Typically, for simplicity, multiple linear regression analyses are used to develop the transfer function.

The process involves the selection of potentially significant parameters each of which should be independent from the others. Through the use of a stepwise regression process, the most significant variables are included in the equation. By analysing the patterns of the residuals with respect to each variable, it is possible to determine if the variables are behaving in a linear fashion. Curvilinear biases can be corrected by transforming the variables, which can be as simple as taking logarithms of the variables.

Areal bias can be detected by plotting the residuals or more simplistically the signs of the residuals at their station location on a map. This will help determine the homogeneous zones for this particular dependent variable. This process was carried out for all ordinary least squares regressions in this report.

In the next three chapters ordinary least squares regression is used to determine the significant independent parameters affecting the transfer of flood, mean and low flows to ungauged sites and to divide the stations into regions of hydrologic similarity. Generalized least squares are then used to determine the significance of each station to the accuracy of the regression equation and to suggest the types of stations reguired to improve the relationship. Means of transferring daily flow with flow duration curves will also be examined.

4.0 MEAN FLOW ANALYSIS

In order to determine the data transfer abilities of the present network, the first studied flow characteristic was mean flow. The annual mean flow as well as the 2, 20 and 100 year recurrence interval annual mean flows were used to develop regional equations using both ordinary and generalized least squares regression analyses. The latter analysis provided a means of assessing the importance of the stations to the network, a main objective of this project.

4.1 ORDINARY LEAST SQUARES ANALYSIS

In a recent regional flood frequency study for New Brunswick entitled "Flood Frequency Analyses New Brunswick" (Inland Waters/Lands Directorate Atlantic Region and New Brunswick Department of Municipal Affairs and Environment, 1987), 37 stations were selected for analysis using only the 1970-1985 portion of their records. For conformity and convenience, the mean flow study began with the same 37 stations plus three others, once again using the same period of record.

For each of the 40 stations, the annual mean flows were extracted for the 16 years of record 1970-1985, thus giving 40 observation points with a sample size of 16 at each. Prior to performing the frequency analyses, all stations were examined to ensure that the station data sets were independent, random observations from homogeneous, trend-free populations. Program CFA (Pilon et al., 1985) was used, and all sets met all four criteria.

Frequency analyses were then performed using program LP3NET (P.J. Pilon, 1987), which gives output in a convenient form for entry into the Generalized Least Squares (GLS) regression program for network analysis (Thomas et al., 1985). The single station frequency analyses and plots were examined, and all but one were considered satisfactory. It was further considered appropriate to treat the main stem of the Saint John River separately and this excluded another five stations from the analysis, thus reducing the number of stations available to 34. These stations are shown on Figure 4.1 and listed in Table 4.1.

From the 34 single station analyses, the 2, 20 and 100-year annual mean flows were extracted. These were the observations of the dependent variables initially regressed on physiographic and climatic parameters to develop regional ordinary least squares (OLS) equations.

Figure 4.1 Stations Used in Mean Flow Analysis

Table 4.1

Stations Used in Preliminary Regressions
for Mean Flow Analysis

Original Set of Stations

WSC NO.	STREAM NAME	C.S.	C.K.
01AD003	St. Francis River	-0.080	2.502
01AF003	Green River	-0.117	2.194
01AG002	Limestone River	-0.092	3.295
01AJ003	Meduxnekeag River	-0.196	2.764
01AJ004	Big Presque Isle Stream	0.011	3.120
01AK005	North Nashwaaksis Stream	0.300	3.209
01AK007	Nackawic River	-0.269	2.876
01AL002	Nashwaak River	-0.177	3.247
01AM001	Northwest Oromocto River	-0.046	4.076
01AP002	Canaan River	-0.144	4.866
01AP004	Kennebecasis River	0.803	4.292
01AQ001	Lepreau River	0.592	3.089
01AQ002	Magaguadavic River	-0.245	3.232
01AR006	Dennis Stream	0.806	4.050
01BC001	Restigouche River	-0.247	2.384
01BD002	Rivière Matapedia (Québec)	0.376	3.944
01BE001	Upsalquitch River	-0.484	2.910
01BF001	Rivière Nouvelle (Québec)	-0.109	3.333
01BJ001	Tetagouche River	0.462	4.957
01BJ003	Jacquet River	0.771	5.998
01BJ007	Restigouche River	0.647	2.568
01BL001	Bass River	0.570	4.212
01BL002	Rivière Caraquet	0.192	3.875
01BO001	Southwest Miramichi River	-0.428	3.743
01BO002	Renous River	-0.213	3.187
01BP001	Little Southwest Miramichi River	-0.450	3.331
01BQ001	Northwest Miramichi River	-0.719	3.894
01BR001	Kouchibouguac River	-0.221	4.200
01BS001	Coal Branch River	0.051	3.705
01BU002	Petitcodiac River	0.296	4.549
01BU003	Turtle Creek	0.274	3.021
01BU004D	Palmers Creek	0.778	3.442
01BV006	Point Wolfe River	0.367	3.521
01DL001	Kelley River (Nova Scotia)	0.252	3.335

continued...

Table 4.1 (concluded)

Stations Used for Verification

WSC NO.	STREAM NAME	C.S.	C.K.
01AG003	Aroostook River	-0.130	2.884
01AH005	Mamozekel River	0.035	3.644
01AJ010	Becaguimec Stream	-0.478	3.416
01AJ011	Cold Stream	-0.221	3.923
01AK008	Eel River (near Scott Siding)	-0.069	3.248
01AN001	Castaway Brook	-0.030	4.342
01AN002	Salmon River	0.050	3.993
01AP006	Nerepis River	0.211	3.219
01AR008D	Bocabec River	0.921	4.509
01BJ004D	Eel River (near Eel R. Crossing)	0.016	3.529
01BL003	Tracadie River	0.158	3.861
01B0003	Barnaby River	0.007	4.106
01BV007D	Upper Salmon River	0.151	4.118

D Discontinued Station
C.S. Coefficient of Skew of Annual Mean Flows
C.K. Coefficient of Kurtosis of Annual Mean Flows

At the present stage of development, the GLS regression program cannot operate in stepwise or backward elimination modes, and the basin characteristics which are the significant independent variables have to be chosen either using hydrologic intuition, or by carrying out an OLS regression using a computer program capable of stepwise or backward elimination methods. Using the SP Statistical Package (Pilon and Cheng, 1987), a regression equation was obtained for the 100-year annual mean flow using drainage area (DA) and mean annual precipitation (MAP). Its standard error of estimate was about 14%.

At this stage, and still only using the 34 stations used for preliminary regression analysis as presented in Table 4.1, a GLS regression equation was derived and its performance was checked by using it to estimate the 100-year annual mean flows at the additional 13 stations, "ungauged sites", not used in the derivation. As an indicator of the performance of the GLS regression equation, percentage deviations of the regression estimate from the "at site" estimate were computed and are shown in Table 4.2.

Table 4.2

Annual Mean Flow Comparisons

100-Year Annual Mean Flows
Comparison of Regression and At-Site Estimates
for
Stations Not Used in Deriving the Regression Equation

	D.A. km^2	M.A.P. mm	Q100 estimate	Q100 at-site	% Deviation
01AG003	6060	934	157	173	- 9.2
01AH005	230	1030	7.31	6.65	+ 9.9
01AJ010	350	1130	12.2	11.40	+ 7.0
01AJ011	156	1100	5.41	4.83	+12.0
01AK008	531	1070	17.2	16.0	+ 7.5
01AN001	34.4	1180	1.35	1.45	- 6.9
01AN002	1050	1130	35.6	37.0	- 3.8
01AP006	293	1140	10.4	11.3	- 8.0
01AR008	43	1180	1.68	2.25	-25.3
01BJ004	88.6	1100	3.12	2.91	+ 7.2
01BL003	383	1090	12.8	13.2	- 3.0
01B0003	484	1080	15.9	15.80	+ 0.6
01BV007	181	1380	8.10	9.97	-18.8

Estimates computed from:

$$Q_{100} = \exp(-11.12 + 0.9804 \ln \text{D.A.} + 1.120 \ln \text{M.A.P.})$$

Predictive Bias = - 2.4% Standard Deviation = 11.3%

Root Mean Square error = 11.1%

As can be seen, the predictive bias of the GLS regression is a mere -2.4%, which means that the regression can be accepted as unbiased for any practical purpose. It will also be noted from Table 4.2 that the deviations cluster closely around the mean, with a standard deviation of about 11%, indicating good precision in the estimates. Thus, one regional regression equation is mathematically appropriate for predicting the mean annual flow of the entire province of New Brunswick.

It is not entirely sufficient that the mathematical bias and precision of the regression equation are satisfactory, because the pattern of areal bias must also be considered. A simple subjective test is to plot on a map the signs of regression residuals at their corresponding stations and look at the overall picture. For mathematical reasons, the OLS residuals must be used, and they are shown plotted on Figure 4.1. A study of this figure shows that negative residuals predominate in the northern half of the province, and this in itself provides a clue to subdividing the province into two regions, northern and southern. A convenient boundary line can be obtained, as shown in Figure 4.2, by starting at the divide between sub-sub divisions 01BR and 01BS at the Northumberland Strait, following this divide to the southernmost divide of the Miramichi basin, then going around the divide to the junction of sub-sub divisions 01BM, 01AJ and 01AH. Finally, strike due west to the Maine-New Brunswick international boundary. By so doing, 22 stations are available in the northern region, and 25 in the southern region. Table 4.3 lists the stations found in each region.

OLS regressions were then re-run for each region, for the 100-year annual mean flow only. Regression equations were obtained with standard errors of estimate of about 10%. It was found that in the northern region, mean annual precipitation was no longer a significant variable at the 5% level. The signs of the regression residuals were then plotted and they showed a more random pattern in their areal distribution.

Figure 4.2 Homogeneous Mean Flow Regions of New Brunswick

Table 4.3

Allocation of Stations by Region

Northern Region

01AD003	01AF003	01AG002	01BC001	01BD002
01BE001	01BF001	01BJ001	01BJ003	01BJ007
01BL001	01BL002	01BO001	01BO002	01BP001
01BQ001	01BR001	01AG003	01AH005	01BJ004
01BL003	01BO003			

Southern Region

01AJ003	01AJ004	01AK005	01AK007	01AL002
01AM001	01AP002	01AP004	01AQ001	01AQ002
01AR006	01BS001	01BU002	01BU003	01BU004
01BV006	01DL001	01AJ010	01AJ011	01AK008
01AN001	01AN002	01AP006	01AR008	01BV007

4.2 GENERALIZED LEAST SQUARES ANALYSIS

Because of the limitations of the existing program GLSNET, it is necessary to prepare input in a special format. Details of the lengthy data preparation process are available elsewhere (Thomas et al, 1985).

Once this was accomplished, a regression for the median annual mean flow in terms of the pre-chosen independent variables, in this case the drainage area and mean annual precipitation, was determined and shown in Figure 4.3 as:

$$Q_2 = \exp(-14.40688 + 1.01324 \ln DA + 1.51366 \ln MAP).$$

One of the advantages of GLS over OLS is that the network can be evaluated according to its ability to estimate the frequency regime of some flow characteristic with an acceptable degree of accuracy. In these GLS evaluations, accuracy is given as average sampling error and average model error; these errors are actually variances, and because of the transformation of the dependent variable to its Naperian logarithm, the percent error can easily be determined. The prediction variance is the sum of sampling and model variances, hence in this case 0.0160, as shown in the second page of the sample output of Figure 4.3. To transform to a percentage, a quick approximation is to simply take the square root and to multiply by 100, which results in a standard error of prediction of 12.6%.

```
PROGRAM GLS     VERSION 03JUL87

SUMMARY OF REGRESSION FOR SIGMA


REGRESSION COEFFICIENTS
 VARIABLE        COEFFICIENT    STANDARD ERROR    T FOR H0:BETA=0     PROB>|T|

 CONSTANT            -0.00024         0.33947         -0.00071
 SIGMA                0.99984         0.21379          4.67671          0.0001

MODEL ERROR FOR SIGMA =    0.00000E+00


SUMMARY OF REGRESSION FOR MEAN


REGRESSION COEFFICIENTS
 VARIABLE        COEFFICIENT    STANDARD ERROR    T FOR H0:BETA=0     PROB>|T|

 CONSTANT          -15.04521         1.96468         -7.65783
 DA                  1.00498         0.02065         48.66815          0.0001
 MAP                 1.60748         0.27099          5.93178          0.0001

MODEL ERROR FOR MEAN =   0.11721E-01

SUMMARY OF REGRESSION FOR  T-YR Q              RECURRENCE INTERVAL =   2.00 (FLOOD FLOW)

          T    -1   -1
        (X (COV  )X)

   CONSTANT        DA             MAP
     3.7522     -0.16659E-01  -0.51673
  -0.16659E-01   0.42679E-03   0.20255E-02
  -0.51673       0.20255E-02   0.71428E-01


REGRESSION COEFFICIENTS
 VARIABLE        COEFFICIENT    STANDARD ERROR    T FOR H0:BETA=0     PROB>|T|

 CONSTANT          -14.40688         1.93705         -7.43754
 DA                  1.01324         0.02066         49.04645          0.0001
 MAP                 1.51366         0.26726          5.66362          0.0001

ESTIMATED RHO BETWEEN MEAN AND STD DEV = 0.00
```

Figure 4.3 Sample GLS Output

NUM	ACTUAL	PREDICTED	VARIANCE OF PREDICTED	RESIDUAL	VARIANCE OF RESIDUAL	STANDARD. RESIDUAL	MODEL ERROR	SAMPLING ERROR	RATIO SAM ER TO V PRED	HAT DIAGONAL	COOKS D
01AJ003	3.300	3.176	0.018	0.124	0.010	1.238	0.012	0.006	0.345	0.211	0.315
01AJ004	2.330	2.195	0.019	0.135	0.009	1.437	0.012	0.007	0.377	0.283	0.550
01AK005	-0.569	-0.314	0.017	-0.255	0.010	-2.564	0.012	0.005	0.294	0.204	1.082
01AK007	1.655	1.687	0.016	-0.032	0.012	-0.287	0.012	0.004	0.258	0.062	0.009
01AL002	3.624	3.717	0.016	-0.094	0.010	-0.952	0.012	0.005	0.289	0.208	0.148
01AM001	2.569	2.675	0.015	-0.106	0.013	-0.949	0.012	0.003	0.226	0.035	0.082
01AP002	2.666	2.699	0.016	-0.033	0.011	-0.317	0.012	0.004	0.268	0.125	0.013
01AP004	3.277	3.407	0.016	-0.130	0.011	-1.261	0.012	0.004	0.263	0.139	0.208
01AQ001	2.024	1.919	0.015	0.105	0.011	0.984	0.012	0.003	0.217	0.081	0.093
01AQ002	3.611	3.648	0.016	-0.037	0.011	-0.362	0.012	0.004	0.276	0.163	0.019
01AR006	1.016	1.087	0.015	-0.071	0.012	-0.659	0.012	0.003	0.225	0.071	0.042
01BS001	1.388	1.334	0.016	0.054	0.011	0.512	0.012	0.004	0.257	0.108	0.032
01BU002	2.136	2.140	0.016	-0.004	0.012	-0.039	0.012	0.004	0.273	0.102	0.000
01BU003	1.323	1.383	0.015	-0.061	0.011	-0.580	0.012	0.004	0.241	0.116	0.038
01BU004	-0.101	-0.080	0.016	-0.021	0.010	-0.207	0.012	0.005	0.279	0.166	0.006
01BV006	1.695	1.479	0.016	0.216	0.010	2.121	0.012	0.005	0.284	0.179	0.673
01DL001	0.676	0.588	0.015	0.088	0.011	0.839	0.012	0.004	0.242	0.115	0.080
01AJ010	2.045	2.170	0.015	-0.124	0.013	-1.087	0.012	0.003	0.219	0.043	0.099
01AK008	2.413	2.509	0.016	-0.097	0.014	-0.818	0.012	0.004	0.247	0.036	0.061
01AN001	-0.078	-0.115	0.016	0.037	0.012	0.335	0.012	0.005	0.286	0.135	0.014
01AN002	3.163	3.283	0.016	-0.120	0.014	-1.025	0.012	0.004	0.254	0.068	0.102
01AP006	1.917	2.003	0.015	-0.086	0.014	-0.732	0.012	0.003	0.216	0.041	0.042
01AR008	0.047	0.111	0.016	-0.063	0.014	-0.526	0.012	0.004	0.271	0.095	0.028
01BV007	1.976	1.804	0.016	0.172	0.010	1.707	0.012	0.005	0.282	0.217	0.441

AVERAGE SAMPLING ERROR 0.0043
AVERAGE MODEL ERROR 0.0117

Figure 4.3 (continued)

Sample GLS Output

Another important function tabulated on the second page of the output is the "hat diagonal", a statistic which, in the context of the GLS analysis, measures how far the physiographic and climatic parameters for each station are from the mean for all stations. Large "hat diagonals" are associated with the stations which make the largest contribution to the reduction in sampling error.

The Cook's D statistic is also useful in assessing the results of the GLS analysis. Cook's D is a "distance" which measures the influence of an observation on the regression: a larger value implies a greater influence of the observation (Draper and Smith, 1981).

4.3 NETWORK ASSESSMENT FOR MEAN FLOW

One of the objectives set for the New Brunswick Hydrometric Network Evaluation Study was the development of a list of the active hydrometric stations in order of priority. Several criteria were to be used to priorize the stations, including the relative importance of a station to provide estimates of mean flow at ungauged sites in New Brunswick. The outputs of program GLSNET and of another program, NETTAG, were used to rate the 46 stations used in this mean flow analysis. The goal was to classify each of the 46 stations as either a "1" (more important) or a "0" (less important); such a classification was for later use in a Station Audit exercise in order to assess the entire network based on a number of factors, one of which is regional hydrology.

Program NETTAG was designed to assess the change in the overall sampling error as the network is projected into the future (a user-specified horizon) and systematically reduced in size, one station at a time. The program uses the "hat diagonal" diagnostic from GLSNET and recomputes the GLS regressions with the least important stations (i.e. the smallest "hat diagonal" value) removed, one at a time. In the one extreme, all of the stations are retained for the next x years; in the other, none of the stations are kept. However, there is an option for the analyst to exclude certain "untouchable" stations from the elimination process. This option is useful if additional criteria (i.e. other than the "hat diagonal" statistic) are to be used to assess a reduced network.

Additional criteria were applied while using the NETTAG program in this study. The general approach taken with each of the four GLS regression results (Table 4.4) was to:

1) identify the four stations which cover the extremes of the climatic/physiographic variables used to develop the regressions - in this case, drainage area and mean annual precipitation; these four stations were declared ineligible for discontinuation by program NETTAG and automatically classified as "1" (more important);

2) run program NETTAG: the first 50% of the stations discontinued plus the next two stations were given a preliminary classification of "0" (less important); the remainder, a preliminary classification of "1" (more important);

3) using the output from GLSNET, to examine the Cook's D statistic for "exceptional" stations which warranted a "1" rather than a "0": if the influence of the station on the regression was relatively large, then the station was considered to be a "1" (more important);

4) to modify the preliminary classifications made with the NETTAG output (Step 2) with the results of Step 3.

The final classification of the 46 New Brunswick stations were input to the Station Audit. This process involved assigning a maximum of 9 points to the regional hydrology priority of which a maximum of 1 point was associated with the importance of the station to transferring mean annual flows. The remaining 8 points were divided among the low and high flows which are admittedly more difficult to transfer and generally of greater importance to the user than the mean.

4.4 SUMMARY

Using OLS and GLS regression techniques, relationships with standard errors most likely acceptable to the majority of users were developed for estimating annual mean flow at ungauged sites in New Brunswick. In addition, the GLS technique provided a crude but objective means of rating the relative importance of each hydrometric station used to develop these relationships.

Table 4.4

GLS Regression Equations for Annual Mean Flow

The 2-year mean flow (exceedance), Q_2

Definition: "There is a 50% probability that the mean flow in any year will equal or exceed Q_2 m3/s."
or
"The median annual flow is Q_2 m3/s."

NORTHERN REGION:

$$Q_2 = \exp(-10.77683 + 1.00638 \ln DA + 0.99196 \ln MAP)$$

S.E.E. = 9.1%

SOUTHERN REGION:

$$Q_2 = \exp(-14.40688 + 1.01324 \ln DA + 1.51366 \ln MAP)$$

S.E.E. = 12.7%

The 20-year mean flow (non-exceedance), $Q_{20}non$

Definition: "There is a 5% probability that the mean flow in any year will be less than or equal to $Q_{20}non$ m^3/s."
or
"The mean flow in 1 year out of 20 will be less than or equal to $Q_{20}non$ m^3/s."

NORTHERN REGION:

$$Q_{20}non = \exp(-12.24306 + 1.01467 \ln DA + 1.14814 \ln MAP)$$

S.E.E. = 10.7%

SOUTHERN REGION:

$$Q_{20}non = \exp(-18.05270 + 1.01399 \ln DA + 1.97914 \ln MAP)$$

S.E.E. = 12.5%

Note: Refer to Figure 4.2 for location of regions
DA = drainage area, in square kilometres
MAP = mean annual precipitation, in millimetres
S.E.E. = standard error of estimate

5.0 LOW FLOW ANALYSIS

The purpose of the low flow analyses portion of the project was to determine the effectiveness of the network in estimating low flows. The basic tool for transferring hydrologic information from the gauged stations of one region to the ungauged stations of that same region is generally through multiple linear regression analysis fit by the method of least squares. To use this method, the basic assumptions of statistical regression analysis must be fulfilled. Sufficient data from a homogeneous region are required to develop the equation and adequately cover the ranges for which the regression equation will be applied.

This analysis was performed in two parts. The first part consisted of Ordinary Least Squares (OLS) regressions of the 1:2 year (median) and the 1:20 year recurrence interval mean 10-day low flows to determine the significant dependant variables and establish the homogeneous regions. The second part assessed the effectiveness of each station in the network to provide estimates of low flows at ungauged sites by analysing their contribution to the estimating function from the results of the Generalized Least Squares (GLS) regression.

The median or 1:2 year recurrence interval 10-day low flow was originally selected for this exercise because the GLSNET program was limited to exceedance events and the median can be taken as both exceedance and non-exceedance. The program was subsequently modified during the study and any return period (exceedance or non-exceedance) could be computed and analysed directly by the GLSNET program opening the door to lowflow analysis. Subsequently, the analysis was expanded to include the 1:10 and 1:20 year recurrence interval flows. These return periods of the mean 10-day low flows were selected because they are generally useful parameters in pollution control and would also demonstrate the ability of the data network to determine the statistical recurrence of low flows at ungauged sites.

5.1 LOW FLOW FREQUENCIES

The regulation of streamflows critically biases low flow data and therefore such station data are not used in regional analyses of low flows. Of the 37 stations used in the updated regional flood frequency analysis, 33 were located on unregulated streams. The elimination of regulated stations from the analysis left only one of the main stem stations on the Saint John River. Consequently,

it was not possible to determine if a region could be made for the stations on the main stem of the Saint John River as will be the case in the high flow analysis.

Following the procedures used in the annual mean flow analysis, only the 1970-1985 portion of the records from these stations were used. Later, 12 other suitable stations with a shorter period of record were added to the analysis. The list of stations used is given in Table 5.1 and their locations can be determined by referring back to Figure 4.2 on page 18.

Table 5.1

Stations Used in Regression Analysis of 10 - Day Mean Low flows

Initial Set of 33 Stations

01AD002	01AD003	01AG002	01AJ003	01AJ004	01AK001
01AK007	01AL002	01AL003	01AM001	01AP002	01AP004
01AQ001	01AR006	01BC001	01BD002	01BE001	01BJ001
01BJ003	01BJ007	01BL001	01BL002	01BL003	01BO001
01BO002	01BP001	01BQ001	01BR001	01BS001	01BU002
01BU003	01BU004	01BV006			

Additional Set of 12 Stations

01AH005	01AJ010	01AJ011	01AK008	01AL004	01AN001
01AP006	01AR008	01BJ004	01BO003	01BV005	01BV007

For each of the 33 stations, 10-day mean low flows were computed for the 16 years of record 1970-1985. The data sets were not subjected to the non-parametric tests to assess problems of stationarity, trend and homogeneity as were the annual high and mean flows. No problems were anticipated in light of the analyses performed in the other studies. Low flow frequency analyses were performed using the LP3NET program. The OLS and GLS regressions were performed on data from the same LP3 distribution in order to provide a basis for comparison.

Separately, the low flows from 12 additional stations, were analysed for testing the regression equations. Some of these were previously discontinued, however, all have shorter periods of record within the same time frame.

5.2 ORDINARY LEAST SQUARES ANALYSIS

As explained in the annual mean flow analysis, the OLS regression is used to determine the significant independent variables from the menu of parameters provided. The 2 and 20 year mean 10-day low flows were extracted from the output of the LP3NET analyses and input as observations of the dependent variables. These were then regressed against independent physiographic and climatic parameters applicable to each station watershed.

The parameters tested for significance in the stepwise elimination process of the regression analysis were: drainage area (DA), annual base flow index (BFI), seasonal base flow index (BFIS), mean annual precipitation (MAP), areal percent of lakes and swamps (%LS), snow pack as water equivalent on March 31 (SLUSH), and latitude (LAT) and longitude (LONG) of the hydrometric gauge. Preliminary analysis had eliminated numerous other parameters as they were shown to be not significant or less significant than other parameters which correlated well with the above list. For example, since drainage area and basin perimeter are highly correlated, including both in a regression equation would invalidate the assumption of parameter independence. Each of the parameters retained were tested in various transformed modes and checked by the scatter of the residuals to determine if the data appeared to meet the basic assumptions of regression analyses.

The values of the physical parameters along with at-site statistical parameters from the low flow frequency analysis for each station are then retained for use in the GLS regressions to be performed later.

Using the Statistical Package (SP) (Pilon and Cheng, 1987), regression equations for the entire province were obtained for the Q_2 and Q_{20} mean 10-day low flows, first using the original 33 stations. Three paramaters were found to be significant at the 5% level: Naperian logarithms of drainage area, the base flow index and the Naperian logarithms of mean annual precipitation. The coefficients of determination (r^2) and the standard errors of estimate (S.E.E.) found for these equations were as follows:

10-DAY MEAN LOW FLOW (33 stations)		
Q_2 -	r^2 = .973	S.E.E. = 30.1%
Q_{20}-	r^2 = .940	S.E.E. = 50.0%

To test the equations, the physiographic and climatic parameters from the 12 additional stations, which had less than the 16 years of data, were input to the regression equations and treated as "ungauged stations". The percent deviation between the regression flows and the "at-site" estimates from LP3NET are shown in Tables 5.2 and 5.3. They indicate that, with the exception of a few stations, the equations were reasonably good and that these additional 12 stations should be added to the regression analysis. These additional stations are especially of great benefit to the GLS analysis. However, the resulting equations now show coefficients of determination and standard errors of estimate as follows:

10-DAY MEAN LOW FLOW (45 stations)

Q_2 -	$r^2 = .974$	S.E.E. = 29.7%
Q_{20}-	$r^2 = .927$	S.E.E. = 55.7%

While the statistics for the Q_2 equation are virtually unchanged, those from the Q_{20} equation show a wider variance. This could be due to the shorter periods of record used in the frequency analysis to determine 1:20 year recurrence interval low flows, which would be more sensitve at the larger return period or it could be reflecting the natural variation that could be masked by the smaller 33 station sample. As a final check, the pattern of areal bias of the residuals from the Q_{20} equation was plotted by simply indicating whether it was positive or negative at the station location as shown on Figure 5.1. From this figure, it can be seen that the equation underestimates the flow in the relatively flat Maritime Plain region and overestimates the flow in the southwestern part of the province.

Checks on the areal bias of the equation showed regions of similarity in the Maritime Plain, the southern coastal highlands and on a north/south basis on the remaining stations. Equations were developed along these regional divisions or homogeneous low flow regions as shown in Figure 5.2. The standard errors of the regressions were generally much better than those from the equations for the entire province, the exception being the Western Region which interestingly enough has the greatest number of stations. This variability can be attributed to the complexity of the physiography of this area. In general, the main problem with these equations is the limitation in the ranges of their parameters and the small sample size (number of stations) in each region. The primary deficiency (Western Region excepted) appears to be the lack of small drainage

Table 5.2

Comparison of Simulated Q_2 Lowflows

Calibration Stations

Station Number	Drainage Area(km^2)	Q_2 at-site	Q*33 estimate	Q*45 estimate	% Deviation *33	% Deviation *45
01AD002	14700.0	38.000	35.277	34.423	-6	-8
01AD003	1350.1	4.300	4.915	4.619	14	7
01AG002	199.0	0.550	0.351	0.333	-35	-39
01AJ003	1210.0	1.680	1.875	1.820	12	8
01AJ004	484.0	1.110	0.725	0.685	-34	-37
01AK001	234.0	0.410	0.651	0.637	59	55
01AK007	240.0	0.140	0.253	0.266	81	90
01AL002	1450.0	5.010	4.329	4.497	-13	-9
01AL003	6.5	0.030	0.026	0.024	-14	-17
01AM001	557.0	0.590	1.076	1.124	82	90
01AP002	668.0	0.770	0.764	0.797	0	3
01AP004	1100.0	3.720	3.011	3.110	-18	-15
01AQ001	239.0	0.850	0.581	0.610	-31	-27
01AR006	115.0	0.110	0.193	0.202	75	84
01BC001	3159.9	10.800	10.446	10.465	-2	-2
01BD002	2770.0	9.570	8.882	8.434	-6	-11
01BE001	2269.9	6.650	9.145	8.678	38	31
01BJ001	363.0	0.760	0.857	0.799	13	5
01BJ003	510.0	1.190	0.930	0.927	-21	-21
01BJ007	7740.3	25.800	24.716	24.878	-3	-3
01BL001	175.0	0.150	0.192	0.195	28	30
01BL002	173.0	0.810	0.738	0.690	-8	-14
01BL003	383.0	1.700	2.160	1.943	27	14
01BO001	5049.8	22.800	16.336	16.096	-27	-28
01BO002	611.0	1.900	1.938	1.950	2	3
01BP001	1340.0	6.420	6.832	6.607	6	3
01BQ001	948.0	3.100	3.313	3.233	7	4
01BR001	177.0	0.500	0.460	0.435	-7	-12
01BS001	166.0	0.290	0.259	0.262	-10	-9
01BU002	391.0	0.560	0.445	0.458	-20	-17
01BU003	129.0	0.430	0.517	0.530	20	23
01BU004	34.2	0.060	0.044	0.048	-25	-19
01BV006	130.0	0.550	0.403	0.438	-26	-19

continued...

Table 5.2 (concluded)

Verification Stations

Station Number	Drainage Area(km^2)	Q_2 at-site	Q*33 estimate	Q*45 estimate	% Deviation *33	% Deviation *45
01AH005	230.0	0.560	0.529	0.504	-5	-9
01AJ010	350.0	0.730	0.564	0.590	-22	-18
01AJ011	156.0	0.290	0.339	0.336	17	16
01AK008	531.0	0.800	1.670	1.587	109	98
01AL004	3.9	0.010	0.010	0.010	-1	-2
01AN001	34.4	0.100	0.080	0.081	-19	-18
01AP006	293.0	0.400	0.305	0.336	-23	-15
01AR008	43.0	0.060	0.093	0.094	54	57
01BJ004	88.6	0.170	0.140	0.142	-17	-15
01BO003	484.0	0.730	0.795	0.812	9	11
01BV005	29.3	0.100	0.087	0.094	-12	-5
01BV007	181.0	0.710	0.535	0.585	-24	-17

Q_2 = at-site 1:2 year low flow from frequency analysis

Q*33 = estimated flow from regression based on 33 stations

Q*45 = estimated flow from regression based on 45 stations

*33 = deviation in percent of observed from Q*33

*45 = deviation in percent of observed from Q*45

Table 5.3

Comparison of Simulated Q_{20} Lowflows

Calibration Stations

Station Number	Drainage Area(km^2)	Q_{20} at-site	Q*33 estimate	Q*45 estimate	% Deviation *33	% Deviation *45
01AD002	14700.0	26.900	17.216	13.801	-35	-48
01AD003	1350.1	2.440	3.404	2.888	40	18
01AG002	199.0	0.330	0.146	0.108	-55	-66
01AJ003	1210.0	0.590	0.889	0.632	51	7
01AJ004	484.0	0.370	0.457	0.286	24	-22
01AK001	234.0	0.120	0.195	0.206	63	72
01AK007	240.0	0.030	0.071	0.065	136	116
01AL002	1450.0	2.800	1.907	2.286	-31	-17
01AL003	6.5	0.020	0.018	0.020	-8	0
01AM001	557.0	0.130	0.204	0.244	57	88
01AP002	668.0	0.240	0.260	0.227	9	-4
01AP004	1100.0	1.890	1.572	1.751	-16	-6
01AQ001	239.0	0.210	0.117	0.160	-43	-23
01AR006	115.0	0.020	0.043	0.050	114	149
01BC001	3159.9	7.680	6.875	6.928	-9	-9
01BD002	2770.0	5.010	6.169	5.041	23	1
01BE001	2269.9	3.820	8.586	7.391	125	93
01BJ001	363.0	0.370	0.657	0.464	78	25
01BJ003	510.0	0.620	0.486	0.413	-21	-32
01BJ007	7740.3	15.500	16.275	15.999	5	3
01BL001	175.0	0.030	0.055	0.046	85	54
01BL002	173.0	0.460	0.302	0.310	-33	-32
01BL003	383.0	0.930	1.931	1.677	108	80
01BO001	5049.8	16.200	8.216	7.939	-48	-50
01BO002	611.0	0.990	0.635	0.749	-35	-23
01BP001	1340.0	4.120	3.131	3.608	-23	-11
01BQ001	948.0	1.800	1.577	1.614	-11	-9
01BR001	177.0	0.260	0.172	0.152	-33	-40
01BS001	166.0	0.150	0.088	0.081	-40	-45
01BU002	391.0	0.220	0.239	0.189	9	-13
01BU003	129.0	0.250	0.284	0.380	14	52
01BU004	34.2	0.030	0.018	0.020	-40	-32
01BV006	130.0	0.210	0.125	0.204	-39	-2

continued...

Table 5.3 (concluded)

Verification Stations

Station Number	Drainage Area(km^2)	Q_{20} at-site	Q*33 estimate	Q*45 estimate	% Deviation *33	% Deviation *45
01AH005	230.0	0.340	0.557	0.405	64	19
01AJ010	350.0	0.290	0.264	0.261	-8	-9
01AJ011	156.0	0.100	0.268	0.232	168	132
01AK008	531.0	0.170	0.601	0.568	253	234
01AL004	3.9	0.010	0.005	0.006	-46	-40
01AN001	34.4	0.050	0.024	0.027	-52	-45
01AP006	293.0	0.050	0.095	0.101	91	101
01AR008	43.0	0.010	0.026	0.030	159	199
01BJ004	88.6	0.110	0.076	0.069	-30	-37
01BO003	484.0	0.330	0.201	0.200	-38	-38
01BV005	29.3	0.060	0.019	0.034	-67	-43
01BV007	181.0	0.340	0.185	0.293	-45	-13

Q_{20} = at-site 1:20 year low flow from frequency analysis

Q*33 = estimated flow from regression based on 33 stations

Q*45 = estimated flow from regression based on 45 stations

*33 = deviation in percent of observed from Q*33

*45 = deviation in percent of observed from Q*45

Figure 5.1 Pattern of Areal Bias of Residuals from Q_{20} 10-Day Mean Low Flow Equation

Figure 5.2 Homogeneous Low Flow Regions of New Brunswick

areas. Interestingly enough, the Western Region equations have the greatest error and also the best range of station parameters. One conclusion from this is that the region is not as homogeneous as anticipated and indeed it is probably the most complex in its physiography.

It is evident from looking at the parameter list regional equations in Table 5.4 that the regions appear to be different and that using the equations for the entire province would not be desirable. For example, only Western Region considers the parameter "percent of lakes and swamps plus 1" as significant yet the provincial equation for Q_{20} contains that parameter. The inclusion of this parameter in the "province-wide" equation results in some dramatic changes in how certain stations fit in the respective equations. For example, using the province-wide equations, with station 01AH005, Mamozekel River, results in an underestimate of 9% based on the 1:2 year low flow equation but an overestimate of 174% based on the 1:20 year low flow equation. The reason for this is the extremely low percentage of lakes and swamps in the watershed in comparison with the rest of the stations. Part of the variance can be attributed to the parameters presently available for regression, but the mix of stations must play an important role as will be shown in the GLS regressions.

Because there appears to be a lack of data from small watersheds, it was decided to assess the influence of basin size in estimating low flows. The set of 45 stations, minus station 01BD002 which is in Quebec, was divided into a group containing the 22 largest basins and another with the 22 smallest basins. Regression analysis for the 2 year low flow was performed with the previously mentioned climatic and physiographic parameters for the two groups resulting in the equations in Table 5.5.

Comparing each of those equations with the corresponding equation in Table 5.4, it can be seen that the smaller basins, as indicated by the larger standard error their equations produce, account for more variability than the larger ones. Furthermore, the lower r^2 for the smaller basin equation with only drainage area, as compared to the r^2 for the corresponding equation for larger basins, appears to indicate that drainage area explains less of the low flow variability in smaller basins than in larger basins. The greater regression coefficient for BFI for the smaller basin equation with both drainage area and BFI, as compared to the corresponding coeffient for larger basins, appears to indicate that geology, as represented by BFI, is a more significant cause of low flow variability in smaller basins than in larger basins.

Table 5.4

Comparison of Regression Equations

Low Flow Regression Analyses Equations
by
Ordinary Least Squares and Generalized Least Squares
Multilinear Regression

$$Q_2 = \exp(k + a \ln DA + b\ BFI + c \ln MAP + d \ln (\%LS+1))$$

Region	Type	k	a	b	c	d	r^2	S.E.E.
Province	OLS	-27.23965	0.95948	4.96495	2.67258	-	.974	29.7
n=45/44*	GLS	-26.85338	0.94952	4.84852	2.58678	-	-	29.9
Southern	OLS	-37.01000	1.20678	-	4.22052	-	.995	10.4
n=8	GLS	-35.48862	1.16990	-	4.04307	-	-	9.3
Western	OLS	- 8.27119	0.93521	5.52868	-	-0.37035	.978	29.0
n=13	GLS	- 8.25974	0.95111	5.82360	-	-0.48901	-	23.9
Eastern	OLS	-33.51852	0.96101	5.076940	3.56260	-	.989	19.1
n=12	GLS	-32.27712	0.95716	5.27459	3.37306	-	-	22.7
Northern	OLS	- 6.49740	1.08444	-	-	-	.993	15.7
n=11	GLS	- 6.47186	1.08010	-	-	-	-	17.3

Q_2 - 1:2 year 10-day mean low flow (m/s^3)

n - no. of stations in sample

DA - drainage area above stream gauge site (km^2)

BFI - base flow index

MAP - mean annual precipitation (mm)

%LS+1 - percentage of drainage area comprised of lakes and swamps (plus 1)

OLS - ordinary least squares regression fitting method

GLS - generalized least squares method fitting method

S.E.E. - standard error of estimate (%)

* - The province-wide equation for OLS used all 45 stations; however, one station affected the matrix algebra in the GLS solution and had to be dropped from further analyses.

continued...

Table 5.4 (concluded)

$Q_{10} = \exp(k + a \ln DA + b\ BFI + c \ln MAP + d \ln (\%LS+1))$

Region		k	a	b	c	d	r^2	S.E.E.
Southern n=8	GLS	-40.83258	1.20786	-	4.67747	-	-	18.1
Western n=13	GLS	- 9.92904	0.96138	8.59201	-	-0.86666	-	27.4
Eastern n=12	GLS	-40.37280	0.97177	6.51133	4.34439	-	-	35.2
Northern n=11	GLS	- 7.04756	1.10066	-	-	-	-	19.5

$Q_{20} = \exp(k + a \ln DA + b\ BFI + c \ln MAP + d \ln (\%LS+1))$

Region		k	a	b	c	d	r^2	S.E.E.
Province	OLS	-27.957	0.89171	8.65881	2.49995	-0.35417	.927	55.7
n=45/44	GLS	-26.26584	0.93342	7.09919	2.35718	-0.32216	-	54.4
Southern	OLS	-40.52116	1.14636	-	4.64177	-	.967	26.7
n=8	GLS	-38.32151	1.17568	-	4.35020	-	-	25.1
Western	OLS	-10.76922	0.82943	10.2541	-	-0.70978	.918	57.6
n=13	GLS	-10.36315	0.96124	9.32858	-	-0.97345	-	32.9
Eastern	OLS	-54.24755	0.98848	6.95746	6.24407	-	.965	40.8
n=12	GLS	-43.30605	0.98164	6.87938	4.70375	-	-	40.3
Northern	OLS	-7.17060	1.10553	-	-	-	.990	19.3
n=11	GLS	-7.20511	1.10777	-	-	-	-	20.3

Table 5.5

Low Flow Regression Analyses
for Small and Large Basins

(1:2 Year Recurrence Interval 10-Day Low Flow)

Smaller Basins ($3.89\ km^2 \leq DA \leq 350\ km^2$)

$Q_2 = \exp(-5.499 + 0.869 \ln DA)$

$r^2 = .792$ S.E. = 59.3%

$Q_2 = \exp(-7.921 + 0.842 \ln DA + 5.210 BFI)$

$r^2 = .876$ S.E. = 45.8%

$Q_2 = \exp(-29.514 + 0.935 \ln DA + 5.631 BFI + 2.969 \ln MAP)$

$r^2 = .933$ S.E. = 33.7%

Larger Basins ($363\ km^2 \leq DA \leq 14700\ km^2$)

$Q_2 = \exp(-7.345 + 1.193 \ln DA)$

$r^2 = .901$ S.E. = 43.8%

$Q_2 = \exp(-8.969 + 1.047 \ln DA + 4.565 BFI)$

$r^2 = .953$ S.E. = 30.2%

$Q_2 = \exp(-8.363 + 1.015 \ln DA + 4.451 BFI - .220 \ln(\%LS+1))$

$r^2 = .966$ S.E. = 26.3%

$Q_2 = \exp(-19.917 + 1.014 \ln DA + 4.183 BFI - 0.206 \ln(\%LS+1) + 1.674 \ln MAP)$

$r^2 = .974$ S.E. = 23.4%

5.3 GENERALIZED LEAST SQUARES ANALYSIS

In order to perform the GLS regression analyses, the standard deviation of the log-transforms of the mean 10-day low flow data for each station were taken from the LP3NET program output and used as the dependent variable of a regression called the SIGMA regression. The purpose of this step was to determine the significant parameters of the standard deviation (SIGMA) as input to the GLS regression.

The data were run using the GLSNET program as described in the earlier sections. The resulting regression equations are shown in Table 5.4 and show slight improvements in the standard error with the exception of the Northern Region equations which displayed 1 to 1.5% increases in the error.

One of the output parameters of the GLSNET program was the "hat diagonal " which can be used to rank the importance of each station to the estimating function. The main assumption of the analysis is that the stations are all from the same hydrologic region. The distribution of the hat diagonals from the Eastern and Northern Regions appeared to show no strong bias in ranking the stations i.e. there was no singling out of areas or stations which displayed extreme characteristics within the region, referred to during the exercise as "odd-ball" stations for lack of a better term. However, the Southern Region appeared to be divided along the 01AQ/01BV and 01AP/01BU division boundaries and Western Region showed the 01AL division stations all high ranking and the 01AR-01AP basin stations low ranking. The other parameter was Cook's D, an influence statistic which ranks the importance or influence that the station has on the relationship; consequently, a station with a high Cook's D would be more important than one with a lower value.

It must be stressed that it is not just a simple job of ranking the stations according to the magnitude of the above parameters and then proceeding to the final network design. One of the major assumptions of the analysis is that the stations are from a homogeneous hydrologic region, the definition of which can only be speculated with the sparse data available. Therefore, all of the information at hand must be used, from the knowledge of the hydrometric technician through to the station characteristics, coupled with some basic theory of hydrometric design to question any peculiar ranking trend. In the end, all of this information is used to rank the stations' importance to the network. Because of the problems noted with the Southern and Western Regions, it was decided not to apply some of the more sophisticated priority ranking options of the GLSNET program.

With the exception of the Western Region regression equation, the standard errors, although below what is perceived by the user as acceptable, appear to be appropriate. This is especially so when compared with those equations developed for drier areas of the United States (Thomas and Benson, 1970) where the low flows are possibly much smaller, have a greater error associated with them and the effective area contributing groundwater flow might be significantly different from the surface drainage area.

Stations are ranked on a maximum of 4 points based on their relative importance to the low flow regression equations and these scores added to the regional priority code.

5.4 SUMMARY

From the data available there appear to be four hydrologic regions reflecting the characteristics of the low streamflow regime. The delineation of these regions are shown on Figure 5.2. As to the true homogeneity of these regions, there are some questions that remain due to a lack of data. These questions are especially noticable in the Southern and Western Regions for which there still appears to be some bias among various groups of stations.

Low flows appear to be more variable in smaller basins where geology seems to have a greater impact than in larger basins. This variation between small streams is primarily due to the discrete differences in geology whereas a large basin will have a range of geological conditions over its area. Thus, more small basins are needed to define this variability as well as to extend the range of the regression equations to the range of the typical size of streams that are of greater interest for water supply and fisheries management.

6.0 HIGH FLOW ANALYSIS

In order to determine the effectiveness of the New Brunswick hydrometric network in estimating high flows at ungauged sites, the results from a previous study entitled "Flood Frequency Analyses New Brunswick" (Inland Waters/Lands Directorate - Atlantic Region and New Brunswick Department of Environment and Municipal Affairs, 1987) as well as the analysis described below using Generalised Least Squares (GLS) regressions were employed. The previous study generated regional flood frequency equations using Ordinary Least Squares (OLS) based on 37 stations with a concurrent period of record from 1970 to 1985. Along with equations for the 2, 10, 20, 50 and 100 year floods for the entire province, New Brunswick was divided into four homogeneous flood regions, shown in Figure 6.1, for which regional equations were also generated. The main stem of the Saint John River was considered a fifth region because of the overwhelming size of the drainage areas in comparison to other streams in the province.

6.1 GENERALIZED LEAST SQUARES ANALYSIS

For the present project, which used GLS, regional equations were developed for the 2, 20 and 100 year floods for the four homogeneous flood regions determined in the previously mentioned study, with the OLS equations indicating the significant independent variables for the GLS regressions. The climatic and physiographic parameters derived in the previous study were used, but 44 stations were employed to develop the regional equations in this study. While stations in Maine and Nova Scotia were ignored, additional stations with at least 10 years of record, but without a complete record from 1970 to 1985, were also considered. The entire period of record was used for all stations, which are listed in Table 6.1. The output from program LP3NET provided the mean, standard deviation and coefficient of skew required for the analysis. Details of the GLS programs are given in Chapter 4.

As shown in Table 6.2, the resulting regression coefficients from both analyses can differ significantly at times. The GLS coefficients for drainage area, however, are never greater than unity. A value of "a" greater than 1.0 in the equation $Q = z\ DA^a\ MAP^b$ would imply that a given increase in area leads to a larger increase in flow, which would not make physical sense. One cannot expect to double the drainage area and obtain more than twice the flood flow.

Another observation about the GLS results, is that the

Figure 6.1 Homogeneous High Flow Regions of New Brunswick

Table 6.1

Hydrometric Stations Used in GLS Flood Frequency Equations

01AD002	01AD003	01AG002	01AH005
01AJ003	01AJ004	01AJ010	01AK001
01AK007	01AK008	01AL002	01AL003
01AL004	01AM001	01AN001	01AP002
01AP004	01AP006	01AQ001	01AR006
01AR008	01BC001	01BD002	01BE001
01BJ001	01BJ003	01BJ004	01BJ007
01BL001	01BL002	01BL003	01BO001
01BO002	01BO003	01BP001	01BQ001
01BR001	01BS001	01BU002	01BU003
01BU004	01BV005	01BV006	01BV007

Eastern region coefficients are closer in value to the ones developed for the other regions. These two findings suggest that the GLS equations, because they took into account the correlation between stations and the different lengths of record, provide more realistic results.

The standard errors of the GLS equations vary from region to region as shown in Table 6.3, with the Eastern consistently the lowest and the Northwestern consistently the highest. Given that the standard error of Water Survey of Canada high flow data is accepted at around 10%, the low standard errors of the Eastern region do not mean that the regression equations predict flows at ungauged sites almost as accurately. The standard errors merely reflect how well the regression equations fit the data points and do not incorporate the fact that each single station flood estimate used to develop the regional equations has an error not only dependent on the number of years of record but also on the accuracy of the stage-discharge curve at high flow. Section 2.2 discusses further the accuracy problem associated with single station flood frequency analysis.

6.2 NETWORK ASSESSMENT FOR HIGH FLOWS

The results from the previous study and the analysis for this report lead to a number of observations about the present network and how a more effective network could be implemented. Network modifications, especially the creation of new stations within a particular homogeneous flood region, should ideally occur within the same year so that

Table 6.2

OLS and GLS Flood Frequency Regression Coefficients

$$\ln Q = k + a \ln DA + b \ln MAP$$

2 YEAR FLOOD

	method	k	a	b
Province	OLS	-9.548	0.933	1.206
	GLS	-9.313	0.915	1.177
Eastern	OLS	-1.497	1.001	-
	GLS	-0.980	0.904	-
Central	OLS	-1.313	0.965	-
	GLS	-1.176	0.929	-
Southern	OLS	-24.472	0.894	3.343
	GLS	-19.413	0.871	2.641
Northwestern	OLS	-1.626	0.995	-
	GLS	-1.401	0.953	-

20 YEAR FLOOD

	method	k	a	b
Province	OLS	-14.210	0.910	1.980
	GLS	-12.293	0.909	1.697
Eastern	OLS	0.848	0.684	-
	GLS	-0.068	0.838	-
Central	OLS	-0.438	0.939	-
	GLS	-0.281	0.895	-
Southern	OLS	0.090	0.887	-
	GLS	0.517	0.797	-
Northwestern	OLS	-1.172	1.009	-
	GLS	-1.014	0.977	-

continued...

Table 6.2 (concluded)

100 YEAR FLOOD

	method	k	a	b
Province	OLS	-16.466	0.894	2.355
	GLS	-13.921	0.910	1.958
Eastern	OLS	2.409	0.454	-
	GLS	0.294	0.803	-
Central	OLS	-31.950	0.993	4.456
	GLS	-22.039	0.918	3.119
Southern	OLS	0.373	0.893	-
	GLS	0.788	0.805	-
Northwestern	OLS	-1.029	1.023	-
	GLS	-0.838	0.982	-

Table 6.3

Standard Errors (%) of GLS
Regression Equations

REGION	2 YR	20 YR	100 YR
Province	16	17	17
Eastern	5.7	6.1	6.7
Central	12	15	19
Southern	15	17	19
Northwestern	22	23	24

the new records can be concurrent and contain the same extreme events in order to best serve regional comparisons. The lack of smaller basins resulted in a restrictive range for the development of flood frequency equations. Additional smaller basins are needed to make future regional analyses applicable to more situations. The inability to provide flood estimates for small basins is a serious deficiency of the present network.

The Eastern Region contained four basins of about the same size: 01BS001 - Coal Branch River at Beersville (166 km^2), 01BL002 - Southwest Caraquet River at Burnsville (173 km^2), 01BL001 - Bass River at Bass River (175 km^2), and 01BR001 - Kouchibouguac River near Vautour (177 km^2). There seems to be no need for more basins between 150 and 200 km^2 in this region.

The coverage in the Central Region is geographically incomplete. While there are a number of large gauged basins in the Miramichi and Nepisiguit basins, no information is available on the headwaters. Smaller basins in these areas would also lead to better drainage area coverage for the Central Region equations.

Again, the output from the GLS was used to priorize the stations, using the remaining 4 points from the 9-point Regional Hydrology Priority Code, which was then input to the Station Audit.

7.0 FLOW DURATION ANALYSIS

For operational and planning purposes, sequences of daily mean flows at ungauged sites can be extremely useful. Means of regionalizing flow duration curves were examined in order to determine the possibility of transferring daily mean flows to ungauged sites. Since other investigations (Mimikou and Kaemaki, 1985) have successfully fit a monthly flow duration curve and derived regional equations for the parameters of the fit equation, attempts were made to fit the daily flow duration curve.

Flow duration curves based on a common period of record from 1970 to 1985 for 30 hydrometric stations in New Brunswick were used for curve fitting. Various models were employed, but since the fit was very poor, it was decided instead to fit the turbinable curve as Acres International Ltd (1985) had previously attempted. The turbinable flow of a given discharge is the average discharge which can be passed through the turbine based on all flows less than that given discharge. Figure 7.1 shows the relationship between the probability density function, the flow duration curve and the turbinable flow curve.

Using QT as the ratio of the "turbinable flow to the mean flow" and QD as the ratio of the "discharge to the mean flow", a fifth degree polynomial of the following form was fit to the turbinable flow:

$$QT = A + B\ QD + C\ QD^2 + D\ QD^3 + E\ QD^4 + F\ QD^5 \quad (1)$$

with a corresponding equation for the probability of exceedance as follows:

$$PROB = B + 2\ C\ QD + 3\ D\ QD^2 + 4\ E\ QD^3 + 5\ F\ QD^4 \quad (2)$$

For the case of zero flow, from equation (2), QD must equal zero and the probability of exceedance PROB must be 1.0, which means that B equals 1.0. From equation (1), for a value of QD equal to zero, the turbinable to mean flow ratio QT should also equal zero, leading to A equal to 0.0. Thus, four polynomial coefficients must be estimated when fitting the turbinable flow curve.

7.1 STATION TO STATION COMPARISONS

Given the flow duration curves or the turbinable flow curves at two locations, if one of those locations has a flow series, a flow sequence can be generated at the second location. The flow on a given day at station 1 is divided

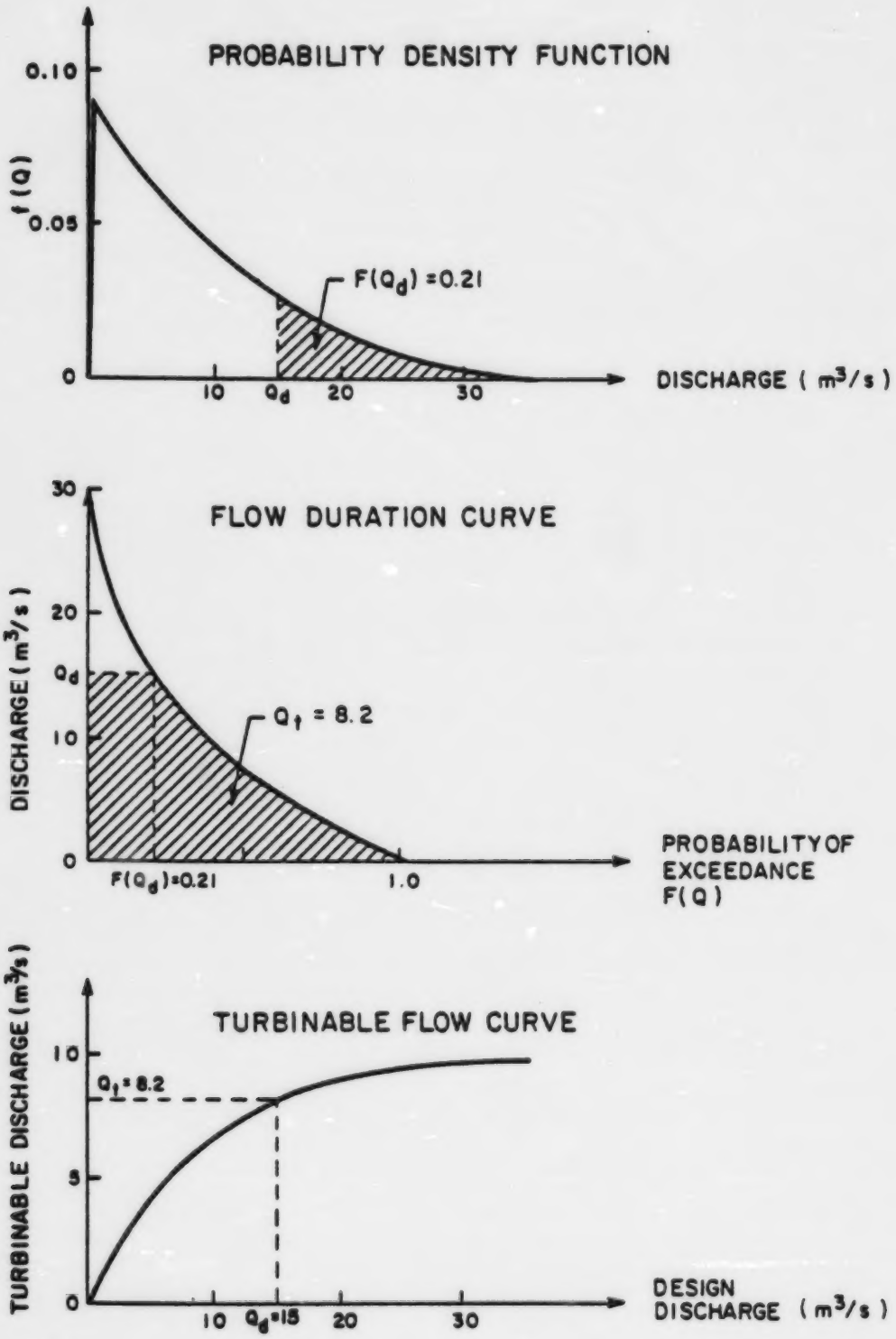

Figure 7.1 Mathematical Interpretation of Turbinable Flow Curve (Acres, 1975)

by the long-term mean at that station to obtain QD. Using the polynomial coefficients along with QD, the exceedance probability of that flow is computed from equation (2). It must then be assumed that on that same day a flow of the same exceedance probability occurred at station 2. Using that probability value and coefficients C, D, E and F for station 2, equation (2) is solved for QD. This value is multiplied by the long-term mean flow at station 2 to generate the flow at station 2 on that day.

Comparisons were made with four sets of stations;
01AQ001 (239 km^2) and 01AR006 (115 km^2),
01BL001 (175 km^2) and 01BL002 (173 km^2),
01AK001 (234 km^2) and 01AK007 (240 km^2),
along with 01BP001 (1340 km^2) and 01BO002 (611 km^2).

In all four cases, the flows at the second station were predicted from the flows at the first station (called the predictant station) using the turbinable flow fits at both stations.

Upon close examination of the recorded and predicted daily flow series at station 2, it was noticed that at flows below the mean flow, the prediction tended to be better than average, while the data transfer technique based on flow duration curves appeared to be less accurate as flows increase. This is due to the spatial variation of precipitation during a storm. On occasion, a very high flow was predicted at station 2 but only a mean flow actually occurred, or vice-versa.

While the flow series generated from flow duration curves cannot mimic exactly the flows of a nearby basin, the mean and standard deviation of the generated flow series are very close to the mean and standard deviation of the recorded flow series as shown in Table 7.1. This means that while the generated series cannot be used for operational purposes, it should be acceptable for planning purposes.

7.2 REGIONAL FLOW DURATION CURVES

In order to generate daily flows at ungauged sites with flow duration curves, the flow duration curve at that site needs to be defined by developing regional equations for the polynomial coefficients of the turbinable flow curve. Parameters C, D, E and F were related to physiographic-climatic variables for 30 basins (Inland Waters/Lands

Table 7.1

Daily Flow Predictions Based on Existing Turbinable Flow Curves

	01AR006	01BL002	01AK007	01B0002
PREDICTANT	01AQ001	01BL001	01AK001	01BP001
AVE. RECORDED FLOW	2.25	2.79	3.55	10.5
AVE. PREDICTED FLOW	2.19	2.52	3.83	11.4
RECORDED FLOW STANDARD DEVIATION	2.83	2.58	5.12	11.4
PREDICTED FLOW STANDARD DEVIATION	2.56	2.76	5.06	13.2

and New Brunswick Department of Municipal Affairs and Environment, 1987) in order to develop regional relationships using factors such as drainage area, mean annual precipitation, percentage of lakes and swamps, and average water content of snow cover.

Using stepwise multiple linear regression, the logarithms of the polynomial coefficients (or a linear variation due to negative values of the coefficients) were related to the logarithms of the physiographic/climatic variables through the following model:

$$\log POCF = a_0 + a_1 \log DA + a_2 \log MAP \qquad (3)$$

where POCF is polynomial coefficient C, D, E or F, DA is the drainage area, and MAP is the mean annual precipitation. The results of this analysis on a province-wide basis using all 30 stations are in Table 7.2.

These regional equations were consequently used to generate regional polynomial coefficients for stations 01AR006, 01BL002, 01AK007 and 01B0002 in order to test their accuracy in generating flows. The results shown in Table 7.3 on page 54 indicate that the regional equations provide predictive accuracy similar to the actual polynomial coefficients at the predicting site, but that the mean and standard deviation of the generated series do not correspond well, except maybe for 01BP001 and 01B0002. Particularly, the mean flows with regional equations were underestimated for the four selected stations.

Table 7.2

Regional Equations for Polynomial Coefficients

$$\log POCF = a_0 + a_1 \log DA + a_2 \log MAP$$

POCF	a_0	a_1	a_2	r^2	S.E.E.(%)
C + 1	-3.650	-	1.060	0.255	18.3
	-4.028	0.045	1.145	0.336	17.5
D	2.596	-	-1.082	0.179	23.9
	3.162	-0.067	-1.209	0.301	22.3
E + 1	-0.140	-	0.041	0.137	1.0
	-0.168	0.003	0.048	0.291	0.9
F	-2.369	-0.146	-	0.147	55.3

7.3 OTHER INVESTIGATIONS

Since Acres International Ltd (1985) had performed regional analysis on the polynomial coefficients of the turbinable flow curves, their analysis was examined more closely. For comparison purposes, their developed regional equations were used to generate turbinable flow curves at stations 01AR006 and 01AK007, which were part of a region for which the equations were available. The Acres regional equations generated daily flow series with mean flows very close to the corresponding recorded mean flows for the same period, but the standard deviations did not correspond at all. A close examination of the entire output of recorded and predicted flows showed that the higher flows tended to be underpredicted.

Since the turbinable flow curve quintic, or fifth degree polynomial, fits are poorer at high flows, it was decided to attempt a quintic fit for sections up to a flow equal to twice the mean flow and then an exponential fit for sections above that threshold. Regional equations were developed for

the coefficients from both equations and these applied to the four stations of interest. This resulted in the mean and the standard deviation of the generated flow series being very different from the recorded.

The large difference in means and standard deviations between the recorded and predicted flow series for the various regional equations from this study as well as from the Acres study would suggest that their use to generate daily flows be avoided. It may well be that variables such as ground water storage, location of tributaries, and location of lakes and swamps have a large influence on flow duration curve shape. If such local factors are so prominent, it may be almost impossible to generate adequate regional flow duration equations for daily flows given the size of network now in place.

7.4 COMPARISON WITH PRORATION

Since the results from regional flow duration curves were so poor, they were compared with the use of proration, the most common technique for daily flow generation. A comparison of Tables 7.1 and 7.4 shows that daily flow predictions based on the actual turbinable flow curves at two sites are much better than by proration. However, a comparison of Tables 7.3 and 7.4 indicates that the generated regional flow duration curves are equally as good as proration for daily flow prediction. Thus, the user of a daily flow series for planning purposes at an ungauged site may wish to use both techniques in order to generate flows.

7.5 SUMMARY

Daily flows were transferred with the use of flow duration curves between two gauged sites, but, due to the spatial variability of rainfall during a storm, the predicted flows had large errors, especially at high flows. While the generated flow series cannot be used for operational purposes, depending on the accuracy required, it may be useful for planning purposes. The regional equations developed in this study as well as in the previous Acres study were not considered sufficiently accurate for data transfer to ungauged sites.

Because local factors are so influential in determining flow duration curve shape, it may be almost impossible to generate adequate regional flow duration curve equations for daily flows. This means that for locations where daily mean flows are required by users on a regular basis, only hydrometric stations can fill that need.

Table 7.3

Daily Flow Predictions With Regional Polynomial Coefficients

	01AR006	01BL002	01AK007	01BO002*
PREDICTANT	01AQ001	01BL001	01AK001	01BP001
AVE. RECORDED FLOW	2.25	2.79	3.55	7.21
AVE. PREDICTED FLOW	1.70	2.15	3.04	7.20
RECORDED FLOW STANDARD DEVIATION	2.83	2.58	5.12	9.46
PREDICTED FLOW STANDARD DEVIATION	1.86	2.70	3.25	8.97

* BECAUSE OF CURVE FITTING PROBLEMS, FLOWS GREATER THAN 2.5 TIMES THE MEAN FLOW WERE NOT USED.

Table 7.4

Daily Flow Predictions with Proration

	01AR006	01BL002	01AK007	01BO002
PREDICTANT	01AQ001	01BL001	01AK001	01BP001
AVE. RECORDED FLOW	2.25	2.79	3.55	10.5
AVE. PREDICTED FLOW	2.92	1.77	4.03	11.8
RECORDED FLOW STANDARD DEVIATION	2.83	2.58	5.12	11.4
PREDICTED FLOW STANDARD DEVIATION	2.51	3.01	3.82	10.7

8.0 SMALL WATERSHED INVESTIGATION

As shown in Chapter 6, regional flood frequency relationships can be derived from streamflow records and measurable basin characteristics related to physiography and climate. These provide the most convenient and widely applied technique for estimating flood frequencies in engineering hydrology.

Such relationships, however, are strictly applicable only within the range of parameters sampled, and would not be applied to basins that are significantly larger or smaller than those used to develop the relations. Typically, most hydrometric stations monitor basins larger than 200 km^2 because of the greater economic and water resources importance of larger streams. Since the developed regional frequency equations are not applicable to small watersheds, a serious deficiency exists in the present network with regard to small basins. However, a number of estimating methods have been developed.

8.1 HYDROLOGIC MODELLING

An alternative approach to regional equations is to compute the rate of runoff from a real or assumed design storm rainfall according to hydrologic properties of the basin such as infiltration and land use characteristics. These techniques range from simple ones such as the Rational Method to more complex hydrograph models such as the SCS technique, OTTHYMO, and the HSPF model (Haan et al, 1982). A variety of useful manuals and guides are available to assist the user.

However, good quality recorded hydrographs and rainfall hyetographs are seldom available with which to calibrate and apply these models, and this is a general deficiency in their application. It is suggested that a program to measure runoff from representative small rural and urban basins in key parts of the province would greatly assist those designers, municipalities and provincial agencies who must rely on hydrologic models. The details of such a program would depend upon local priorities, but as a minimum would include a set of measured flood hydrographs, rainfall hyetographs, and prevailing land use data on several types and sizes of small basins in various segments of the province. The program could operate seasonally using part-time staff, and the results could be built into a concise but very useful document for province-wide application. Data from existing gauges would be included in the program.

8.2 EXISTING RAINFALL INTENSITY DATA

In order to implement the small basin program, the location of 11 existing rainfall intensity gauges in New Brunswick were found (see Table 8.1) and their sites plotted on 1:50,000 scale maps with the drainage basins they monitored delineated.

It quickly became apparent that the majority of the rainfall intensity gauges were at locations of little use for hydrology. The four airports (Chatham, Charlo, Saint John and Moncton) are located on flat topped hills and the drainage is unclear. At Mount Carleton, the gauge is located in a valley near a river outlet into a lake and therefore not representative of the higher terrain. At Sussex, the gauge is in an urban area where drainage is uncertain due to storm sewerage systems.

Two of the rainfall intensity gauges, however, were co-located with existing hydrometric stations. The Nashwaak Project gauge is sited within the drainage area of hydrometric station 01AL004, Narrows Mountain Brook near Narrows Mountain, while the Royal Road gauge is within the drainage area of station 01AK005, North Nashwaaksis Stream near Royal Road. Furthermore, the Salmon DCP rain gauge is close enough to station 01AN001, Castaway Brook near Castaway, to make it a prime candidate for investigating the use of this rainfall data for modelling flow at station 01AN001.

Two rainfall intensity gauges also suggest locations for the gauging of small basins. For the Centreville gauge, a station on Stewart Brook, perhaps up to 20 km^2, could be established. Unfortunately, this basin belongs to physiographic-climatic zone 5, where many stations currently exist and the largest proportion of small basins is located. For the Fredericton CDA gauge, a station on Corbett Brook around 15 km^2 could be investigated. Although it is partly urbanized, Corbett Brook can be recommended as a new station.

8.3 DATA COLLECTION PLATFORMS

Since it is possible to locate a rainfall intensity gauge within one kilometre of a data collection platform (DCP), the location of all existing hydrometric station DCPs in New Brunswick were determined, as listed in Table 8.2. Their surrounding areas were then examined for a small basin with a conveniently sited rainfall gauge within the watershed.

Table 8.1

Rainfall Intensity Gauges in New Brunswick

Climate Station Name	Location			
	Latitude		Longitude	
	deg.	min.	deg.	min.
Chatham A	47	01	65	27
Charlo A	48	00	66	20
Mount Carleton	47	26	66	55
Nashwaak Project	46	17	67	01
Centreville	46	26	67	41
Salmon DCP	46	17	65	43
Royal Road	46	03	66	43
Fredericton CDA	45	55	66	37
Sussex	45	43	65	32
Saint John A	45	19	65	53
Moncton A	46	07	64	41

Table 8.2

New Brunswick DCP Stations

Station Number	Name
01BQ001	Northwest Miramichi R. at Trout Bk.
01BV006	Point Wolfe R. at Fundy Park
01BL003	Tracadie R. at Murchy Bk. Crossing
01BE001	Upsalquitch R. at Upsalquitch
01AJ004	Big Presque Isle Str. at Tracey Mills
01AR006	Dennis Stream near St. Stephen
01AF007	Grand R. at Violette Bridge
01AN002	Salmon R. at Castaway
01AK001	Shogomoc Str. near Trans Canada Hwy
01AD003	St. Francis R. at Outlet of Glasier Lake
01BJ007	Restigouche R. above Rafting Ground Bk.

Since a rainfall intensity gauge would have to be located within one kilometre of the DCP, only station 01BQ001, Northwest Miramichi River at Trout Brook, was suitable for small basin co-location. A rainfall gauge could be sited within Copps Brook, which is part of the Northwest Miramichi River system, where a flat basin up to 17 km^2 in area with some lake and swamp could be located. Unfortunately, this is within physiographic-climatic zone 12 where there already exists a small basin, 01BK006, Forty Mile Brook at Caribou Depot.

An option to obtain usable small basin information would be to arrange for a moving rainfall intensity gauge that would follow a small basin program which collects a few hydrographs at selected sites. The other possibility would be to assure that new stations for small basins have a rainfall intensity gauge with their DCP.

The importance of the small watersheds to the regional hydrology was input to the Station Audit by assigning additional points to those stations with a drainage area of less than 100 km^2.

8.4 SUMMARY

Three stations contain hydrometric information to derive hydrographs given knowledge on hyetographs; namely 01AL004, 01AK005 and 01AN001. One small basin, Corbett Brook, could be proposed for the hydrometric network and it would use available rainfall intensity data.

An effort should be made to obtain more information on the hydrology and climatology of small drainage basins in New Brunswick. Further cooperation and contacts with the Atmospheric Environment Service are definitely required.

9.0 REGIONAL HYDROLOGY NETWORKS

9.1 HOMOGENEOUS HYDROLOGIC REGIONS

From the mean flow, low flow and high flow regional analyses discussed respectively in Chapters 4, 5 and 6, it was determined that certain areas of the province could be grouped into homogeneous mean flow, low flow or flood regions as shown respectively in Figures 4.1, 5.1 and 6.1. Examination of those three figures reveals that the homogeneous hydrologic regions are not identical, which is not surprising as different factors affect different components of the flow regime.

To obtain the homogenous hydrologic regions of New Brunswick, the three groups of regions were first overlayed. While a number of large regions became apparent, there existed smaller areas which, it was felt, could not function as independent hydrologic regions because of their size. In order to aggregate them to larger regions, the relevant physiographic-climatic parameters for stations in those smaller areas were input to the developed regional low flow and high flow equations for the larger adjacent regions. Based on which region these stations appeared to belong, the final seven hydrologic regions of Figure 9.1 were delineated.

Two regional hydrology networks were formulated, one based on the 16 physiographic-climatic zones (the details of their determination are available in an accompanying report) and the other on the seven hydrologic regions. These proposals sought means to efficiently transfer data as well as to incorporate the need for information on small basins, which has been raised in previous sections.

9.2 MINIMUM REGIONAL HYDROLOGY NETWORK

The minimum regional hydrology network consists of at least three stations per physiographic-climatic zone (one small, one medium, one large) in order to permit proration for daily flows, low flows, mean flows and high flows based on a station within the same zone. Because proration is best done with basins of similar sizes, three basins of different size were felt to be a minimum number to represent a zone, although some larger and more complex zones such as Zone 5 would probably require a greater number of stations.

Since the approach of three basins per zone would involve fewer stations, it was selected as the criteria of the minimum network that would permit the determination of flows

Figure 9.1 Homogeneous Hydrologic Regions of New Brunswick

at ungauged sites with a hopefully acceptable level of accuracy. Based on user needs and on the major streams that are still not monitored in New Brunswick, specific locations were chosen for the new hydrometric stations identified in an accompanying report that were needed to achieve the minimum network.

The minimum network is expected to present problems in data transfer accuracy because no two basins are exactly alike. A particular basin in a given zone may be different from another within that zone and the proration of low flows or flood flows may thus be erroneous. Furthermore, it is well known that proration is more accurate between basins of similar sizes, with ideally a difference in area no greater than 20%. With only three stations per zone, an areal difference above 100% for proration would likely be common.

9.3 TARGET REGIONAL HYDROLOGY NETWORK

A better approach is to define larger homogenous hydrologic regions for which regional equations can be developed. As long as care is taken to select representative basins in the region and to assure a proper range of physiographic and climatic parameters, especially drainage area, this method is expected to be superior to the proposed minimum network.

The target regional hydrology network consists of at least 10 stations per hydrologic region, which would be sufficient to permit the development of regional equations fulfilling the requirements of statistical theory. It is necessary to provide five stations per significant physiographic-climatic parameter in order to maintain the degrees of freedom required by statistical theory, and since two parameters were typically found in the regional studies, a minimum of ten stations are needed per hydrologic region.

This superior target network should, of course, fully circumscribe the proposed minimum network. Thus, starting with the minimum network, additional stations were added, based on criteria discussed below, in order to achieve the target network. Table 9.1 presents the proposed minimum and target networks.

Because hydrologic regions A and B were so large, it was decided to permit 15 stations in each of these regions in order to accomodate the three stations per physiographic-climatic zone. Six stations were allowed in region G

Table 9.1

Target Regional Hydrology Network

	STATION/STREAM	D.A.(km^2)	MINIMUM NETWORK
REGION A			
ZONE 16	01AE001	2260	yes
ZONE 14	01AD003	1350	-
	01BC001	3160	yes
	01BJ007	7740	yes
	Iroquois R.	<200	yes
	Kedgwick R.	400-1000	yes
	Gounamitz R.	<200	-
ZONE 9	01AF007	339	yes
	01AG002	199	yes
	Siegas R.	<100	yes
ZONE 10	01AH005	230	yes
	01BE001	2270	yes
	Upsalquitch	500-1000	yes
	lower Tobique	<100	yes
ZONE 15	01BJ012	43.2	yes
REGION B			
ZONE 12	01BK006	13.0	yes
	01BQ001	948	yes
	Nepisiquit R.	250-500	yes
ZONE 11	01BP001	1340	yes
	01BO001	5050	yes
	01BO002	611	yes
	Tuadook R.	<100	yes
ZONE 6	Cains R.	>500	yes
	Cains R.	100-500	yes
	South Branch Renous	<100	yes
ZONE 5	01AJ010	350	-
	01AJ011	156	-
	01AL002	1450	yes
	01AL003	6.48	yes
	01AL008	641	-

continued...

Table 9.1 (continued)

	STATION/STREAM	D.A.(km^2)	MINIMUM NETWORK
REGION C			
ZONE 13	01BL001	175	-
	01BL002	173	yes
	01BL003	383	yes
	01BO004	316	-
	upper Tracadie	<100	yes
	Tabusintac R.	<120	-
ZONE 15	01BJ001	363	-
	01BJ003	510	yes
	01BJ010	190	yes
	01BJ011	123	-
REGION D			
ZONE 7	01AN001	34.4	yes
	01AN002	1050	yes
	01AP002	668	yes
	lower Canaan	<100	-
ZONE 8	01BO003	484	yes
	01BR001	177	-
	01BS001	166	yes
	01BT001	32.1	yes
	Kouchibouguac R.	<100	-
	Tantramar R.	<100	-
REGION E			
ZONE 3	01AP004	1100	yes
	01BU002	391	yes
	01BU003	129	yes
	Trout Creek	80	yes
	Memramcook R.	<150	-
ZONE 4	01BV006	130	yes
	01BV005 restart	29.5	yes
	01BV008 restart	287	yes
	Shepody R.	<80	-
ZONE 1	01AQ001	239	yes

continued...

Table 9.1 (concluded)

	STATION/STREAM	D.A.(km^2)	MINIMUM NETWORK
REGION F			
ZONE 2	01AM001	557	yes
	01A0009	93.2	-
	01AP006	293	yes
	Corbett Brook	15	yes
	Nerepis tributary	<100	-
ZONE 1	01AQ008	197	-
	01AR006	115	yes
	Digdeguash R.	>500	yes
	01AR008 restart	43.0	yes
ZONE 5	01AK005	26.9	-
REGION G			
ZONE 5	01AJ003	1210	yes
	01AJ004	484	-
	01AK001	234	yes
	01AK007	240	-
	01AK008	531	yes
	Keswick R.	>500	-
REGION S			
ZONE 14	01AD002	14700	yes

Note: "yes" signifies the station is part of the minimum regional hydrology network.

because it was so small and because it was partly in Maine where additional stations would be available. Regions C, D, E and F each contain 10 stations. The total number of stations for the target network was 77 compared with 54 for the proposed minimum network.

9.4 SENSITIVITY ANALYSIS

The assumptions on the number of hydrometric stations per physiographic-climatic zone or per hydrologic region in order to establish the minimum and the target networks cannot be modified without affecting the accuracy of the transferred data that will ultimately be available from these networks.

In the minimum network, using only one or two stations per physiographic-climatic zone would severely restrict the ability to prorate because of enormous differences in drainage area. Conversely, having four or more stations per zone, as long as a proper range of basin size was maintained, would greatly enhance the ability to prorate accurately.

In the target network, less than ten stations per hydrologic region would make it impossible to incorporate two physiographic parameters in developing regression equations because five stations per parameter are needed to maintain the required degrees of freedom. A regional equation with a single parameter has a much greater standard error than one with two parameters. If there existed less than five stations per hydrologic region, no meaningful regression equation could be developed for that region because of the degrees of freedom requirement; instead, the seven regions would have to be grouped into larger regions. And thus, regional equations with standard errors much larger than those available in this study would be developed.

Thus, ten stations per region represent the minimum required to develop reasonable regression equations for the seven hydrologic regions. Providing more than ten stations per region would be beneficial primarily because it would increase the already very small sample size currently available for regression equation development. Should reaching fifteen stations per region be considered a target, it would then be possible to employ three physiographic parameters in the equations, which would lead to further refinements of the data transfer functions.

9.5 COMPARISON WITH PRESENT NETWORK

The minimum regional hydrology network presented in Table 9.1 requires 54 stations, 37 of which are part of the present New Brunswick hydrometric network. While there currently exists at least one station in each of the 16 zones, an average of slightly over one new station is required in each zone to achieve the minimum network. Of the 17 new stations needed to obtain that minimum network, nine stations are for small basins less than 100 km^2.

The target regional hydrology network also presented in Table 9.1 requires 77 stations, 51 of which are part of the present network. This represents all 54 natural flow stations presently in New Brunswick except for 3 which were deemed redundant for regional hydrology purposes. Of the 26 new stations needed to obtain the target network, 14 are small basins.

More than half of the new hydrometric stations needed to achieve the minimum regional hydrology network should be located in small basins, a component of the network where there is a severe deficiency. In too many instances, users lack stations of an appropriate size nearby in order to prorate flows or must use regional equations outside the range from which they were developed. This is particularly true for small basins.

The addition of small basins would greatly improve the regional hydrology information presently available in the network, and it should be the first priority in siting new stations. In this respect it is not a matter of what degree of accuracy is lost if these stations are not in the network but whether or not the information can be provided with any credibility.

9.6 INPUT TO THE STATION AUDIT PROCESS

In order to determine the relative importance of each hydrometric station of the regional hydrology network, a rating system was developed. This was necessary in order to provide the regional hydrology input to the overall network evaluation process, called the Station Audit exercise. This overall evaluation process also considered site characteristics, economic activity, federal and provincial commitments, special needs, regional and operational users, and whether the station was part of the minimum and target networks.

On the basis of the analyses performed in Chapters 4, 5 and 6, the importance of each individual station to the regional hydrology network was assessed and points assigned to an input parameter to the Station Audit process. This parameter, called the Regional Hydrology Priority Code, was given a total possible value of 9 points. It was determined from the importance of the station to the hydrology of low, mean and high flows as determined through the GLS regressions as well as the range of the significant physiographic-climatic parameters in the regression equations. It was thought that additional hydrometric data from the stations with the highest and the lowest values for the relevant physiographic-climatic parameters in each region would be of greatest value to the regional hydrology, because they helped to maintain a maximum applicability of the equation.

For the remaining stations that were used to develop the regional equations, it was thought that the difference between the predicted and the actual flows would yield an indication as to the usefulness of the stations in demonstrating the variability within the region. For example, the error between the predicted 20 year flood and the actual 20 year flood was computed and a rating based upon it. For the stations with a record too short to include in the development of the regional equations, a rating was provided depending on their basin size. A subjective rating was also determined based on how close the physiographic and climatic characteristics, including drainage area, of a given hydrometric station were to the other hydrometric stations nearby.

Values up to 4 points were assigned to the station with respect to its importance in transferring data for both low and high flows, whereas only 1 point was awarded to a station important to mean flow estimation. The results from the flow duration analyses were inconclusive and consequently were not included in the evaluation of the priority code. The resulting Regional Priority Codes are summarized in Table 9.2.

The importance of small basins to the regional hydrology network were input directly to the Station Audit by assigning points to these under the special needs category. The assignment was made by the members of the committees during discussions of various elements of the Station Audit.

TABLE 9.2

REGIONAL HYDROLOGY PRIORITY CODES INPUT TO STATION AUDIT

REGION	STATION NUMBER	DRAINAGE AREA	PRIORITY CODE	STATION NUMBER	DRAINAGE AREA	PRIORITY CODE
A	01AD002	14700	9	01BJ007	7740	8
	01BC001	3160	8	01BJ012	43.2	8
	01BE001	2270	8	01AD003	1350	7
	01AF007	339	7	01AH005	230	7
	01AG002	199	9			
B	01BO001	5050	8	01AL002	1450	7
	01BP001	1340	8	01BQ001	948	7
	01AL008	641	4	01BO002	611	7
	01AJ010	350	3	01AJ011	156	5
	01BK006	13.0	8	01AL003	6.5	9
	01AL004	3.9	0			
C	01BJ003	510	5	01BL003	383	7
	01BJ001	363	7	01BO004	316	6
	01BJ010	190	5	01BL001	175	9
	01BL002	173	7	01BJ011	123	7
	01BJ004	88.6	-			
D	01AN002	1050	7	01AP002	668	6
	01BO003	484	7	01BR001	177	4
	01BS001	166	3	01AN001	34.4	8
	01BT001	32.1	6			
E	01AP004	1100	8	01BU002	391	7
	01AQ001	239	9	01BV007	181	-
	01BV006	130	8	01BU003	129	8
	01BU004	34.2	-	01BV005	29.3	-
F	01AM001	557	8	01AQ008	297	4
	01AP006	293	8	01AR006	115	7
	01A0009	93.2	8	01AR008	43.0	-
G	01AJ003	1210	8	01AK008	531	8
	01AJ004	484	8	01AK007	240	7
	01AK001	234	5			

Note: "-" denotes a discontinued station which was not included in the station audit process

10.0 CONCLUSIONS AND RECOMMENDATIONS

By continuing the monitoring of streamflows in New Brunswick, important information needed for the well-being of the economy as well as the environment will be collected. The findings and recommendations that follow point out directions for hydrometric network improvements that will benefit all inhabitants of the province.

10.1 MAJOR FINDINGS AND RECOMMENDATIONS

1. Lack of coordination exists between meteorologic and hydrometric data in New Brunswick. Co-location of small basins and rainfall intensity data is needed to make optimum use of small basin hydrometric information. Cooperation with the Atmospheric Environment Service should increase in order to provide more temperature, precipitation and snow cover data useful for flow modelling purposes. This is especially needed for small basins so that transferable hyetograph/hydrograph relationships can be developed.

2. The network is expected to fulfill all user needs for mean annual flow. The standard errors for the low flow and flood frequency equations provided here are comparable to other studies. However, lower standard errors, which are attainable by the addition of new stations to the network, are desirable.

3. Because of the restrictive drainage area range of all developed regional equations, additional hydrometric stations to monitor flows from small basins should be established so that the equations can be applicable under a greater number of circumstances.

4. Three small basins exist for which the availability of meteorological data makes the investigation of modelling not only hydrographs but also the entire flow regime a worthwhile endeavour. These are:
   - 01AL004 - Narrows Mountain Brook
   - 01AK005 - Middle Branch Nashwaaksis Stream
   - 01AN001 - Castaway Stream.

5. Station coverage is incomplete in the central portion of the province. Additional hydrometric stations should be established there.

6. Only the establishment of new hydrometric stations can provide daily flows at ungauged sites with the accuracy required by most users. Such data is typically needed for operational uses such as dam operations and water supply management.

7. Seventeen (17) new hydrometric stations are required to provide the proposed minimum regional hydrology network. Twenty-six (26) new hydrometric stations are required to achieve the target regional hydrology network. Network managers should first implement the minimum regional hydrology network, and next strive to establish the target regional hydrology network presented in this report.

8. Of the 54 active natural flow stations, 3 are of little value to regionalization because the flows measured are not fully representative of the actual runoff from their drainage area over the complete flow regime, their natural characteristics have been altered significantly, or they are similar in size and characteristics to a nearby basin. Their usefulness towards the other main network requirements should be assessed. These are:

   01AR012 - Chamcook Stream
   01AK005 - Middle Branch Nashwaaksis Stream
   01AL004 - Narrows Mountain Brook.

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